

The relationship between motor proficiency, bilateral vestibular hypofunction and dynamic visual acuity in children with congenital or early acquired sensorineural hearing loss

Compiled by
Wilhelmien Geldenhuys

GLDWIL003

A DISSERTATION SUBMITTED TO THE
UNIVERSITY OF CAPE TOWN
in fulfilment of the requirements for the degree
Master of Science in Physiotherapy

Faculty of Health Sciences
UNIVERSITY OF CAPE TOWN

Supervisor: Prof Jennifer Jelsma

Co-Supervisor: Mrs Christine Rogers

Division of Physiotherapy

School of Health and Rehabilitation Sciences

Faculty of Health Sciences

University of Cape Town

October 2010

Declaration

I, W. Geldenhuys, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work or any part of it has been, is being, or is to be submitted for another degree at this or any other university.

I empower the university to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever.

Signature

Date

Acknowledgements

My sincere thanks and appreciation go to the following people for their contribution to this study:

- Professor Jennifer Jelsma, for her invaluable guidance and assistance to make the completion of this study possible, and also for her help with the statistical analysis
- Mrs Christine Rogers, for her prompt reading, constructive criticism, advice and encouragement throughout the study
- The principals of Sonitis and Eduplex, who gave permission for the study to be conducted at the two schools
- Mrs Celeste Mulder from Sonitis, for her cooperation in organising the selection of children from the school
- Ms Marelize Oosthuizen from Eduplex, for her willingness to help with the selection of the hearing-impaired group and assistance to find appropriate normal-hearing matches
- Dr Louis Hofmeyr, for his help with the inter-rater reliability of the SCPNT
- Mrs Annemarie Kirsten, for her willingness to help with the reliability study
- Professor Marié de Beer, for her expertise and patience in explaining the statistical analysis of the results
- Jackie Viljoen and Lorraine Osman, for the editing of the dissertation
- The parents and the children, whose cooperation made this study possible
- My family and friends, for their interest and encouragement
- My husband Dirk, for his encouragement and sacrifices
- My children, Lourens and Lauré, who sometimes had to play without me
- My Creator, who gave me the ability to complete the study

Abstract

The functional integrity of the vestibular system in children is not often tested. Due to the close relationship between the cochlea and the peripheral vestibular system, the function of the vestibular system may be impaired in children with sensorineural hearing loss.

The aims of this study were to determine the prevalence of impairments of motor performance, vestibular function and dynamic visual acuity, and the nature and extent of interaction between these in children between the ages of four and fourteen years with congenital and early acquired sensorineural hearing loss.

This research utilised a quantitative, correlational, cross-sectional, descriptive design. Thirty-two children with sensorineural hearing loss were matched with children with no hearing impairment according to age and gender. Motor performance was evaluated by means of the Movement Assessment Battery for Children-2, dynamic visual acuity was determined by means of the Dynamic Visual Acuity Test, and vestibular function with the Southern California Postrotary Nystagmus Test. The performances of the two groups on the different tests were then compared.

The one-sided chi-square test or Fisher's exact test was used to determine any association between sensorineural hearing loss and vestibular hypofunction and poor dynamic visual acuity. The Mann-Whitney U-test was used to determine the difference between children with and without vestibular hypofunction, and between children with sensorineural hearing loss and those with normal hearing on the Movement Assessment Battery for Children-2. Forward stepwise regression was used to establish the predictors of the Movement Assessment Battery for Children-2 total standard score. The Kruskal-Wallis test was used to compare scores of children with normal hearing and those with a mild to moderate sensorineural hearing loss on the Movement Assessment Battery for Children-2.

Bilateral vestibular hypofunction as determined by the Southern California Postrotary Nystagmus Test and an increased dynamic visual acuity score are associated with sensorineural hearing loss. Motor performance is dependent on dynamic visual acuity, degree of sensorineural hearing loss and bilateral vestibular hypofunction.

Children with sensorineural hearing loss should be evaluated for the presence of vestibular hypofunction, dynamic visual acuity abnormality and motor deficits.

Glossary of terms and abbreviations

Caloric testing: Type of vestibular function test in which warm and cool water or air is introduced into the external ear canal to stimulate the horizontal semicircular canal. This test may be administered at the bedside, in the office or in a laboratory. Caloric irrigation is inherently limited by the effectiveness of heat transfer between the external and inner ear. The advantage of caloric testing is that it allows for each horizontal semicircular canal (SCC) to be evaluated separately, leading to the identification of asymmetrical function (Fife et al., 2000).

Cochlea: Inner ear structure that senses sound (Northern & Downs, 2001).

Crista ampullaris: Blood vessels, nerve fibres and supporting tissue of the hair cells in the ampullae of the semicircular canals (Hain & Helminski, 2007).

Cupula: A diaphragmatic membrane that overlies the supporting tissue (crista ampullaris) of the hair cells of the semicircular canals (Hain & Helminski, 2007).

Dynamic visual acuity (DVA) test: Measures visual acuity during head movements. It is presumed to be a functional measure of the vestibular ocular reflex (VOR), which can be used as an outcome measure (Longridge & Mallinson, 1987; Rine & Braswell, 2003). Rine and Braswell (2003) found the test-retest reliability for SVA and horizontal DVA to be excellent with ICC=0.94 and 0.84 respectively, as well as the inter-rater reliability with ICC for SVA=0.93 and for horizontal DVA=0.88. Sensitivity, specificity, positive and negative predictive values for BVH were 100%, regardless of age (ANOVA $p=0.007$) (Rine & Braswell, 2003). The DVA test is therefore a stable measure for the paediatric population (Rine & Braswell, 2003).

Electronystagmography (ENG): Laboratory test that measures eye movements and oculomotor function, which consists of a sub-test of tests, which include caloric tests, positional testing, and visual tracking tasks. Sensitivity and specificity of the test are limited (Fife et al., 2000). See also **videonystagmography (VNG)** below.

Frenzel lenses: 20-diopter lenses used to block visual fixation. Focal length is several centimetres. The advantage is that these lenses allow observation of nystagmus by magnifying the image of the eyes (Levy, Proctor & Holzman, 1997). They also reveal nystagmus, which may otherwise be suppressed by fixation (Honrubia, 2000; Levy et al., 1997).

Gain: To maintain gaze stability (visual acuity) during head movements, the eye movements must be of equal amplitude and speed, but in the opposite direction to the head movement. The gain of the vestibular ocular reflex (VOR) is defined as the ratio of eye movement to head movement velocity (eye velocity/head velocity). The ideal gain to maintain gaze stability is 1. Motion of retinal images must be less than 2°/second for normal vision to be maintained, otherwise visual acuity will be reduced (Hain & Helminski, 2007).

Gaze stability: To maintain gaze stability an image must be projected on the fovea of the retina during head movements (Herdman & Clendaniel, 2007). The function of an intact VOR is to maintain gaze stability through rapid compensatory eye movements during head movements (Schubert & Shepard, 2008).

Labyrinth: Inner ear, which is divided into bony and membranous components. The bony labyrinth occupies the lateral portion of the petrous part of the temporal bone. It is composed of three parts: the cochlea, the vestibule and the semicircular canals. The bony labyrinth is filled with perilymph. The membranous labyrinth is a series of communicating membranous sacs and ducts that are contained in the cavities in the bony labyrinth, and generally follows the form of the bony labyrinth. The membranous labyrinth is filled with endolymph. The receptors of vestibular input in the form of linear and angular acceleration are the sensory hair cells located in the SCC and otoliths (Hain & Helminski, 2007). The cochlear labyrinth contains sensory epithelium that is the receptor of auditory stimuli (Northern and Downs, 2001).

Movement Assessment Battery for Children-2 (M-ABC-2): Assessment tool for the evaluation of mild to moderate motor impairment in children (Henderson, Sugden & Barnett, 2007). The Intra-Class Correlations (ICC) for inter-rater reliability for the M-ABC-2 exceeded 0.95 and ranged between 0.92 and 0.98 for test-retest reliability (Chow & Henderson, 2003). The M-ABC-2 is therefore a reliable measure of motor performance in children.

Nystagmus: Involuntary, rhythmic oscillation of the eyes. It may be physiologic or pathologic. It may be induced by visual (optokinetic) or vestibular stimulation (caloric, rotary or linear acceleration). Pathological nystagmus can be spontaneous, positional or gaze-evoked (Honrubia, 2000). Post-rotary physiological nystagmus is an indication of an intact VOR (Rine, 2007). In cases of reduced vestibular function,

upon attempting to induce nystagmus physiologically via rotation, the velocity of the slow phase of nystagmus and duration of nystagmus will be reduced, or nystagmus will be absent (Rine et al., 2000; Ayres, 1989).

Oscillopsia: “Subjective illusion of visual motion” (Tusa, 2007, p. 111). Oscillopsia differs from vertigo in the sense that it occurs only when the eyes are open, whereas vertigo occurs with eyes closed or open. Severe bilateral loss of the vestibular-ocular reflex (VOR) causes oscillopsia and is described by patients as the jumping of images when the head is moving. This visual blurring is due to the lack of gaze-stabilizing features of the VOR (Tusa, 2007).

Otoliths: Structures within the inner ear that sense linear accelerations (utricle and saccule) (Hain & Helminski, 2007).

Rotary Chair Testing: Vestibular laboratory test used to measure vestibular ocular reflex (VOR). The patient is placed in a chair that rotates under the control of a computer. The eye movements are compared with the head movement to quantify the VOR in terms of gain and time constant of saccadic eye movements (Fife et al., 2000). It is most useful in determining the presence of bilateral vestibular hypofunction (BVH). It is at least as sensitive as caloric testing in determining BVH, and is more specific. However, it is not sensitive in detecting chronic unilateral vestibular hypofunction (UVH) (Fife et al., 2000).

Saccadic eye movement: Rapid eye movement used to shift the eyes to a new target. May be voluntary or involuntary and is generated by cortical and midbrain centres as well as an intact oculo-motor centre in the brainstem (Honrubia, 2000). Saccades can be used to compensate for an aberrant VOR to move the eyes to the target (Schubert 2007).

Saccule: Otolith structure in inner ear that detects linear acceleration in the vertical plane (Hain & Helminski, 2007).

Semicircular canals (SCC): Fluid-filled loops in the inner ear, which sense angular acceleration (Hain & Helminski, 2007).

Sensorineural hearing loss (SNHL): Pathologic changes in the cochlea, its receptors, or along the nerve pathway from the inner ear to the brain stem result in a SNHL. It may be congenital or acquired. SNHL can range in severity from slight to profound (Northern & Downs, 2001). It is generally not amenable to medical

intervention. However, for certain selected cases of severe to profound SNHL, surgical cochlear implantation may be an option (Smith, Bale & White, 2005).

Southern California Postrotary Nystagmus Test (SCPNT): A clinical measure to evaluate post-rotary nystagmus (Ayres, 1989). During axial rotation of a patient, the horizontal SCC and nerve endings are stimulated, which leads to physiological nystagmus in patients with normal vestibular function (Tusa, 2007). Post-rotary nystagmus is an indication of an intact VOR. In patients with reduced vestibular function, the duration of nystagmus will be reduced or nystagmus will be absent (Rine et al., 2000; Ayres, 1989). There is however not consensus on the reliability of the SCPNT (Keating, 1979; Nelson, Weidensaul, Anderson & Shih, 1984).

Utricle: Otolith organ in the inner ear that detects linear translation in the horizontal plane and tilt of the head (Hain & Helminski, 2007).

Vertigo: Illusory sense of motion or rotation of either self or the environment when the eyes are open or closed over which the individual has no control (Leigh, 2007).

Vestibular hypofunction (VH): Reduced function of the peripheral vestibular system. It can be unilateral (UVH) or bilateral (BVH). It may be congenital or acquired (Fetter, 2007). UVH is the result of decreased firing rate of the labyrinth hair cells or one of the vestibular nerves (Leigh, 2007). The symptoms of UVH are mainly vertigo, nausea, vomiting and disequilibrium in the acute stage. Static signs include spontaneous nystagmus, ocular tilt reaction and lateropulsion (patients tend to lean toward affected side). The patient may have vertigo, nystagmus, nausea, vomiting and disequilibrium with the head stationary in acute UVH, which may be aggravated by head movements. With compensation, vertigo and nausea will disappear over the first month or so after the incident that caused UVH. Dynamic symptoms include a decreased dynamic VOR, which means that the patient cannot maintain gaze on a static object while the head is moving. Patients learn to produce a small corrective saccade to compensate for the inadequate dynamic VOR (Curthoys & Halmagyi, 2007). BVH is caused by the loss of tonic and dynamic input from both labyrinths or from both vestibular nerves. In contrast with acute UVH, patients with BVH are more likely to complain of dizziness and unsteadiness than of definite vertigo. One of the main complaints of BVH is oscillopsia. With initial BVH, oscillopsia may be present with the head stationary and unsupported, and it may get worse with head

movements (Herdman & Clendaniel, 2007). Mechanisms found in patients with BVH to improve gaze stability are the change in amplitude of saccades, the use of corrective saccades, modification of pursuit eye movements and the central pre-programming of eye movements (Herdman & Clendaniel, 2007).

Vestibular ocular reflex (VOR): Reflex movement of the eyes in the opposite direction of the head movement. The VOR stabilises gaze in space during head movements (Hain & Helminski, 2007).

Vestibular rehabilitation therapy (VRT): The use of therapeutic exercises to treat vestibular hypofunction (Herdman & Whitney, 2007).

Vestibular spinal reflex (VSR): Reflex movements of the limbs or body to maintain postural stability and balance (Hain & Helminski, 2007).

Videonystagmography (VNG): A small infrared-sensitive video camera is used to determine eye movements during vestibular tests. The advantage of VNG over ENG is that it enables accurate measurement of vertical eye movements. VNG is the preferred method for recording eye movement during vestibular testing (Wuyts, Furman, Vanspauwen & Van de Heyning, 2007).

Table of contentsi

Declaration	i
Acknowledgements	ii
Abstract	iii
Glossary of terms and abbreviations	v
Table of contents.....	x
List of tables	xiii
Table of figures	xvi
Table of appendices	xvii
1 INTRODUCTION	1
1.1 Rationale for the study.....	1
1.2 Studies to determine vestibular function in children.....	3
1.3 Studies to determine motor function in children	6
1.4 Vestibular function and dynamic visual acuity	7
1.5 Research questions	9
1.6 Aim and objectives	10
1.6.1 Aim	10
1.6.2 Objectives.....	10
1.7 Significance of the study.....	11
1.8 Conclusion to introduction	11
2 LITERATURE REVIEW	12
2.1 Introduction.....	12
2.2 Prevalence of SNHL and vestibular hypofunction in children	12
2.3 Anatomy and physiology of the vestibular system	13
2.3.1 The peripheral sensory apparatus	13
2.3.2 The central vestibular system	15
2.3.3 The motor output	15
2.4 Pathology of the vestibular system	17
2.4.1 Causes of vestibular hypofunction.....	17
2.4.2 Pathology associated with SNHL.....	18
2.4.3 Symptoms and signs of vestibular dysfunction	19
2.5 Evaluation of vestibular function	21
2.5.1 Clinical measures of the VOR.....	22
2.6 Assessment of motor system function	28
2.6.1 The Movement Assessment Battery for Children-2 (M-ABC-2)	29
2.7 Studies on motor performance, vestibular function and visual acuity in children with SNHL.....	30
2.7.1 Prevalence studies of vestibular dysfunction in children with SNHL	30
2.7.2 Intervention studies of children with SNHL and associated VH	36
2.8 Conclusion.....	38
3 METHODOLOGY	39
3.1 Research design.....	39
3.2 Hypotheses.....	39
3.3 Research setting.....	39
3.4 Participants.....	40
3.5 Sample size	42
3.6 Instrumentation.....	43
3.6.1 Biographical questionnaire	43
3.6.2 Classification of degree of hearing impairment.....	44

3.6.3	Frenzel lenses	44
3.6.4	The M-ABC-2.....	44
3.6.5	The dynamic visual acuity (DVA) test	45
3.6.6	The SCPNT	46
3.7	Procedure	47
3.7.1	Phase 1	47
3.7.2	Phase 2	48
3.8	Data management	49
3.9	Data analysis	49
3.9.1	Reliability	49
3.9.2	Association between impairments in DVA, vestibular function and motor performance	50
3.9.3	Predictors of M-ABC-2.....	50
3.10	Ethical considerations.....	50
3.11	Physiotherapy in South Africa.....	52
4	RESULTS	53
4.1	Reliability study.....	53
4.1.1	Subject characteristics.....	53
4.1.2	Inter- and intra-rater reliability of the M-ABC-2	53
4.1.3	Inter-rater and intra-rater reliability of the DVA test.....	55
4.1.4	Inter and intra-rater reliability of the SCPNT	57
4.2	Main study	58
4.2.1	Subject characteristics.....	58
4.2.2	Dynamic visual acuity in participants with SNHL	60
4.2.3	Reduced responsiveness to the SCPNT in participants with SNHL	61
4.2.4	Comparison of M-ABC-2 in participants with SNHL with reduced vestibular responsiveness and an increased DVA score	69
4.2.5	Comparison of DVA score in participants with SNHL and normal-hearing participants	73
4.2.6	Comparison of vestibular hyporesponsiveness in participants with SNHL and normal-hearing participants	74
4.2.7	Comparison of M-ABC-2 in participants with SNHL and normal-hearing participants	77
4.2.8	Predictors of performance on the M-ABC-2 in participants with SNHL	81
4.2.9	Predictors of performance on the M-ABC-2 in participants with SNHL and normal hearing.....	82
4.3	Summary of results.....	85
5	DISCUSSION	89
5.1	Short summary of main findings:	89
5.2	Performance of the measurement instruments	90
5.2.1	The M-ABC-2.....	90
5.2.2	DVA test	90
5.2.3	The SCPNT	91
5.3	Prevalence rates of impairments	92
5.3.1	Decreased DVA.....	92
5.3.2	Vestibular hyporesponsiveness	94
5.3.3	Motor impairment.....	96
5.3.4	Association between impairments	96
5.3.5	Prediction of motor impairment.....	98
5.4	Summary of the discussion.....	100

6	CONCLUSIONS AND RECOMMENDATIONS.....	101
6.1	Limitations of the research.....	101
6.1.1	Limitations with regard to the literature review.....	101
6.1.2	Limitations with regard to the empirical study	101
6.2	Recommendations.....	102
6.3	Conclusions	103
	REFERENCES.....	105

List of tables

Table 1: Summary of research findings of prevalence studies of VH in children with SNHL.....	35
Table 2: Summary of research findings of intervention studies in children with SNHL and VH	37
Table 3: Ages in years of participants in the reliability study (N=20)	53
Table 4: Intra-rater ICC values for M-ABC-2 component standard scores and percentiles and overall score (N=20).....	54
Table 5: Inter-rater ICC values, means, SD and range for M-ABC-2 component standard scores and percentiles	55
Table 6: Mean DVA and SVA lines at which three mistakes were made and the DVA score in lines of the raters and the ICC (N=20)	56
Table 7: ICC for duration and number of beats of nystagmus after SCPNT to the left and right (N=20-18).....	58
Table 8: Ages of participants of main study in years	59
Table 9: Degree and frequencies of SNHL.....	60
Table 10: Values of DVA score in participants with SNHL (N=32)	60
Table 11: DVA score and degree of SNHL (N=32))	61
Table 12: Number of beats of nystagmus in ten seconds after rotations to the left (N=32) and to the right (N=30)	64
Table 13: Duration of nystagmus and amount of beats in ten seconds after SCPNT to the left (N=32)	66
Table 14: Duration of nystagmus and number of beats in ten seconds after the modified SCPNT to the right (N=30).....	67
Table 15: DVA score and duration of nystagmus after rotations to the left (N=32)...	68
Table 16: DVA score and number of beats of nystagmus in ten seconds after rotations to the left and right (N=32-30).....	69

Table 17: Means, standard deviations and Mann-Whitney U-statistics of the different components of the M-ABC-2 in participants with SNHL with normal and increased DVA scores (N=32)	70
Table 18: The means, standard deviations of the standard scores and the Mann-Whitney U-statistics of the different components of the M-ABC-2 in participants with SNHL with reduced duration and normal duration of nystagmus after rotations to the left (N=32)	71
Table 19: Means and standard deviations of the different components of the M-ABC-2 in participants with SNHL with less than ten beats and ten or more beats of nystagmus in ten seconds after rotations to the left (N=32)	72
Table 20: Prevalence of impairments in participants with SNHL	73
Table 21: DVA score of participants with SNHL and of normal-hearing participants (N=64)	74
Table 22: Number of beats in ten seconds in SNHL and in normal-hearing groups after rotations to the left and right (N=64).....	76
Table 23: Means and standard deviations of number of beats of nystagmus in ten seconds in participants with SNHL and in normal-hearing participants (N=32–30) ..	76
Table 24: Differences between the means of the different components of the M-ABC-2 in participants with SNHL and their normal-hearing counterparts (N=64)	78
Table 25: The results of the Shapiro-Wilk test for normality	80
Table 26: Comparison of the different components of the M-ABC-2 in the group with SNHL and the group with normal hearing (N=64)	81
Table 27: Predictors of the M-ABC-2 score results of the forward stepwise regression	82
Table 28: Retained variables of the forward stepwise regression	83
Table 29: Summary of number and percentages of participants with impairment on the different tests (N=32–30–32).....	86
Table 30: Abnormal results of participants with SNHL on individual tests	87

Table 31: The predicted score of a 10-year-old child with and without profound SNHL and increased DVA score.....	99
------------------------------------------------------------------------------------------------------------------	----

Table of figures

Figure 1: Scatterplot of the intra-rater DVA test-retest scores in lines (ICC=0.58, N=20, note that some points have multiple cases)	57
Figure 2: Duration of nystagmus in seconds after ten rotations to the left in the group with SNHL (N=32)	62
Figure 3: Duration of nystagmus in seconds after rotations to the right in the group with SNHL (N=30; two children refused to participate)	63
Figure 4: The majority of participants with less than 10 beats of nystagmus after rotations to the left had less than 10 beats of nystagmus after rotations to the right	65
Figure 5: Number of beats of nystagmus in ten seconds after rotations to the left in the normal-hearing group (N=32)	75
Figure 6: Number of beats of nystagmus in 10 seconds after rotation to the right in the normal-hearing group (N=32)	75
Figure 7: Histograms of the total standard scores of the M-ABC-2 in participants with SNHL and normal-hearing participants	79
Figure 8: The difference in means between participants with profound and moderate SNHL and normal-hearing participants (N=64)	84

Table of appendices

A.	Laboratory measures of vestibular function.....	116
B.	Assessment tools for motor function.....	119
C.	Description of test items of M-ABC-2.....	121
D.	Health questionnaire for children with SNHL.....	124
E.	Health questionnaire for normal-hearing children.....	125
F.	Letter of approval from Research Ethics Committee of UCT.....	126
G.	Letter of approval from Sonitis.....	127
H.	Letter to parents of children with SNHL for reliability study.....	128
I.	Assent form for all children.....	131
J.	Letter of approval from Eduplex.....	132
K.	Letter to parents of children with SNHL in mainstream school.....	133
L.	Letter to parents of normal-hearing children in mainstream school.....	136

1 INTRODUCTION

1.1 Rationale for the study

The function of the mature vestibular system is to stabilise the position of the eyes, head and body in space, and to assist in maintaining an upright position (Angeli, 2003; Nandi & Luxon, 2008). The vestibular system is composed of the peripheral and the central components (Hain & Helminski, 2007). The peripheral vestibular system consists of two parts with different functions: the vestibular-ocular system, responsible for gaze stabilisation and clear vision, and the vestibular-spinal system, which contributes to the postural tone necessary for acquisition of motor developmental milestones and also helps to maintain an upright stance (Angeli, 2003). The central vestibular system consists of the vestibular nuclear complex situated mainly in the pons. The vestibular nuclear complex is the primary processor of vestibular input. Concurrently the vestibular nuclear complex contributes to the integration of extra-vestibular information such as visual and proprioceptive input (Schubert & Shepard, 2008). The cerebellum acts as adaptive processor of the nuclear complex of the vestibular system (Hain & Helminski, 2007).

Vestibular disorders are typically perceived as problems affecting only adults (Mehta & Stakiw, 2004) but several investigators have reported vestibular disorders of various aetiologies in children (Crowe & Horak, 1988; Horak, Shumway-Cook, Crowe & Black, 1987; Tsuzuku & Kaga, 1991; Wiener-Vacher, 2008). Despite these reports, the functional integrity of the vestibular system is not often tested in children, and any impairment may therefore go undetected and untreated (Mehta & Stakiw, 2004). It is difficult for most adults to describe the sensations of a vestibular disorder. It may be impossible for children, particularly young children, to describe what they experience. This can be due to a lack of basic communication skills, especially in children with hearing loss (Mehta & Stakiw, 2004).

With an acute unilateral reduction of peripheral vestibular function, children may appear anxious, angry or fearful, clutch at stationary objects, or appear unable to understand what was said because they are unable to describe what they are feeling (Mehta & Stakiw, 2004). These responses may be misinterpreted as a behavioural problem or they could be considered insignificant, leading to misdiagnosis or under-diagnosis (Mehta & Stakiw, 2004). However, in children with congenital or early

acquired vestibular hypofunction (VH), this behaviour would not be expected, because such children have experienced vestibular dysfunction most or all of their lives and may therefore not perceive impaired vestibular sensations as abnormal (Mehta & Stakiw, 2004). It is likely that these children would have bilateral vestibular pathology and therefore they would not experience the symptoms described above.

Children with congenital vestibular abnormalities usually present with delayed gross motor development such as delayed achievement of head control, sitting, standing and walking as well as problems with static and dynamic balance (Angeli, 2003; Kaga, Shino, Jin & Takegoshi, 2008). A child with congenital vestibular failure, for instance, rarely walks before the age of 18 months (Nandi & Luxon, 2008). Late acquisition of developmental milestones in children with congenital vestibular dysfunction is the result of insufficient vestibular input (Kaga, 1999). However, age-expected motor proficiency is often achieved by adolescence as a result of compensation (Angeli, 2003; Kaga, 1999; Kaga et al., 2008). Compensation usually takes place during childhood by using visual and somato-sensory systems (Kaga, 1999; Nandi & Luxon, 2008). In cases where impaired vestibular function was compensated for by other systems, VH may be misdiagnosed or not identified because children demonstrate no outward abnormalities of gait and motor coordination (Rine et al., 2000).

Due to the gaze stabilising function of the vestibular system, children with congenital vestibular abnormalities may have a problem with visual tasks, such as learning to read (Braswell & Rine, 2006a). This may impact on the scholastic performance of children with congenital vestibular dysfunction, which in turn can lead to a reduced quality of life and reduced level of education, which could affect future earning potential (Mehta & Stakiw, 2004).

Due to the close relationship between the cochlea and the peripheral vestibular system with respect to embryology, physiology and anatomy, the function of the vestibular system may be impaired in children with sensorineural hearing loss (SNHL) (Angeli, 2003; Kaga, 1999). Several authors have shown that children with SNHL are more likely to have vestibular impairment than normal-hearing children (Crowe & Horak, 1988; Horak et al., 1987; Selz, Girardi, Konrad & Hughes, 1996).

Children with vestibular dysfunction are not often tested and diagnosed appropriately and they therefore experience several challenges during their development (Kaga et al., 2008; Mehta & Stakiw; 2004). Children with congenital or early acquired SNHL may be at risk of having reduced vestibular function. Research in this field is important to determine the prevalence of vestibular hypofunction in children with SNHL in order to provide suitable intervention.

1.2 Studies to determine vestibular function in children

- Rotary chair testing

Several studies used rotary chair testing as a test for vestibular function in groups of children with SNHL of mixed aetiologies (Crowe & Horak, 1988; Horak et al., 1987; Selz et al., 1996). In general, it was found that approximately two thirds of children with SNHL of mixed aetiologies also have reduced vestibular function. In other words, it was found by the abovementioned authors that vestibular hypofunction is common in children with SNHL, and these findings suggest that vestibular assessment needs to be mandatory in this group.

Crowe and Horak (1988) tested the VOR function of 29 hearing-impaired children and 15 normal-hearing children between the ages of seven and 13 years old by means of rotary chair testing. In the hearing-impaired group, all participants had hearing thresholds greater than 30 dB bilaterally, with nine children's hearing loss resulting from meningitis, one had rubella, four children had congenital SNHL and sixteen children had SNHL due to unknown factors. They found that 66% of the hearing-impaired group had reduced vestibular sensitivity, of which 21% had absent vestibular function, 10% had bilaterally reduced function and 68% had asymmetrically reduced function. These authors did not indicate whether participants with asymmetrical reduced vestibular function had asymmetrical hearing loss as well. In the normal-hearing group, only 13% of children had reduced vestibular function. In other words a high percentage of participants with SNHL also presented with a range of severity of VH, while a much lower percentage of normal-hearing participants showed reduced vestibular function. The reason for some participants with normal hearing presenting with VH might be that rotary chair testing is gold standard and sensitive to even minor, sub-clinical reduction of vestibular function.

Horak et al. (1987) tested 30 hearing-impaired and 54 normal-hearing children aged seven to twelve years by means of rotary chair testing. All children with SNHL had

hearing thresholds greater than 30 dB. Four children had congenital SNHL, ten had hearing loss due to meningitis and 16 children's SNHL was of unknown aetiology. Horak et al. (1987) found that 67% of children with SNHL had an abnormal VOR in comparison with only 7% of normal-hearing children. These findings are similar in the group with SNHL taking part in the abovementioned study. However, fewer participants with normal-hearing in the study of Horak et al. (1987) displayed vestibular involvement than in the the study of Crowe and Horak, 1988. The reason for this lower prevalence might be the fact that the control group of Horak et al. (1987) consisted of 54 participants and the control group of Crowe and Horak (1988) of only 15 participants. As the sample size increases, the variance of the sampling distribution will decrease. This increases the power of normal-hearing participants with normal vestibular function, giving rise to a lower prevalence of normal-hearing children with reduced vestibular function (Lachenicht, 2002).

Selz et al. (1996) tested three groups of children aged eight to 17 years with rotary chair, positional/positioning and eye-tracking testing. The five children in the control group had no history of hearing loss or balance disorders. The two experimental groups consisted of five children with congenital hearing loss in one group and five children with hearing loss due to meningitis before the age of two years in the second group. The researchers found that both deaf groups had gains below normal thresholds during rotary chair testing. Participants with acquired deafness presented with abnormal peripheral vestibular function as demonstrated by the positional/positioning, rotary chair and eye-tracking results. The group with congenital hearing loss displayed results similar to those of the group with acquired hearing loss, but to a lesser degree. This is not surprising because meningitis is a diffuse inflammatory disease, which can affect all areas of the central nervous system. The five participants in the control group had normal results during rotary chair testing. Selz et al. (1996) did not mention how many participants of each deaf group displayed abnormal results and only reported the results of the two groups as a whole. The study of Selz et al. (1996) indicated that children with SNHL are more likely to have vestibular involvement than normal-hearing children and that the pathology that caused the hearing loss affects the degree of vestibular impairment.

- Caloric testing

Reduced vestibular function in children with SNHL was also reported by Tribukait, Brantberg and Bergenuis (2004). These authors used bithermal caloric testing, vestibular evoked myogenic potentials (VEMP) and the subjective visual horizontal (SVH) to test the function of the semicircular canals, the sacculus and the utricle respectively. They tested 36 hearing-impaired children and found that 30% of subjects had abnormal results on all three tests, while 30% had normal results on all three tests. The remaining 40% had abnormal results only in one or two of the tests. This resulted in a total of 70% of the participants with abnormal function of the vestibular system, which may indicate differential sparing of various structures. This is slightly higher than the previously mentioned studies where rotary chair testing was used. The reason for this higher prevalence could be that caloric testing is not sensitive to determine BVH and that rotary chair testing is the test of choice to determine BVH. Caloric irrigation evaluates the function of only one horizontal SCC, in contrast with rotary chair testing that involves both peripheral vestibular systems. The VEMP is a test for the function of the VSR, while rotary chair testing gives an indication of the function of the VOR. Subjective visual horizontal is a subjective test and depends on the interpretation of the examiner. In other words, the tests used in the study by Tribukait et al. (2004) evaluate different parts of the vestibular system than the rotary chair test used in the abovementioned studies.

- SCPNT

Rine et al. (2000) used the Southern California Postrotary Nystagmus Test (SCPNT), which is a clinical test to evaluate the duration and intensity of post-rotary nystagmus. They tested 39 children with SNHL of mixed aetiologies aged between 24 and 83 months. They found that 48% of the children had reduced duration of nystagmus, which is an indication of reduced vestibular function. One possible reason for the lower percentage of children with reduced vestibular function in this study by Rine et al. (2000), in comparison with the other studies, is that rotary chair testing allows for optimal recording of nystagmus and is not impeded by fixation. The SCPNT gives an indication of SCC responsiveness, but nystagmus can be suppressed by fixation because the SCPNT is done with the eyes open in the light. Induced nystagmus in the SCPNT is also subjectively observed and evaluated and not recorded electrophysiologically. Thus, the SCPNT is not as sensitive to

determine reduced vestibular function as the gold standard rotary chair test for BVH and caloric test for UVH.

1.3 Studies to determine motor function in children

Children with SNHL and vestibular deficits present with delayed motor developmental milestones, especially gross motor development, because the vestibular system plays an important role in the reaching of motor developmental milestones and in maintaining balance (Crowe & Horak, 1988; Horak et al., 1987; Rine et al., 2000). Crowe and Horak (1988) reported that the 20 participants with SNHL and reduced vestibular function in their study had significantly lower scores than control subjects on the balance component of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) ($p=0.004$). The participants with SNHL and complete vestibular loss scored worse than the participants with SNHL and reduced vestibular function. This study (Crowe & Horak, 1988) suggested a strong association between SNHL, reduced vestibular function and balance impairment. It also indicated that the degree of vestibular hypofunction plays an important role in the ability to maintain balance.

Horak et al. (1987) found that children with SNHL and reduced vestibular function displayed normal motor performance on the BOTMP, except for the balance component of the test. The control group scored at the 84th percentile in overall motor performance, while the hearing-impaired group with normal vestibular function scored at the 44th percentile, which is near the standard average. The hearing-impaired children with vestibular hypofunction scored only at the 29th percentile because of the low mean balance score. The participants with bilaterally absent vestibular function had the lowest scores on the balance component. The findings of Horak et al. (1987) are similar to the findings by Crowe and Horak, 1988, which indicated that the ability to maintain balance depends on the degree of vestibular function.

The Peabody Developmental Motor Scale (PDMS) was used by Rine et al. (2000) to evaluate the motor performance of 39 children with SNHL. They found that children with SNHL scored lower than normal-hearing peers on the Gross Motor Scale, the locomotor and the receipt and propulsion skill categories ($p\leq 0.01$). The results of repeated measures analysis of variance on 18 participants with SNHL indicated that

motor delay persists or is progressive in children with SNHL, implying that these children are not losing skills, but that development takes place at a slower rate than normal and this makes their scores deteriorate as they get older (Rine et al., 2000). Although the sample size was small (N=18), the study of Rine et al. 2000 supported the idea that children with SNHL and concurrent vestibular hypofunction present with a delay in the development of balance skills.

1.4 Vestibular function and dynamic visual acuity

It can be argued that individuals with SNHL and vestibular system deficits since birth or early in life might also have problems with visual stabilisation, because one of the main functions of the vestibular system is to stabilise the eyes to ensure clear vision during head movements (Angeli, 2003; Nandi & Luxon, 2008). A major complaint of patients with reduced vestibular function, especially bilateral vestibular hypofunction (BVH), is visual blurring with head movements or oscillopsia (Herdman, Hall, Schubert, Das & Tusa, 2007). Oscillopsia is often described by patients as the jumping of images when the head is moving. This visual blurring is due to the lack of gaze-stabilising features of the VOR, which means that the image is not kept stationary on the fovea of the retina (Tusa, 2007). Adults with BVH complain of difficulty reading due to oscillopsia when the head is not supported (Grossman & Leigh, 1990).

Little research has been done on the relationship between BVH and dynamic visual acuity in individuals with SNHL. In children with hearing loss, investigation of the impact of BVH on dynamic visual acuity and reading is important, because of the increased incidence of visual and reading problems in the hearing-impaired group (Braswell & Rine, 2006a). Braswell and Rine (2006a) demonstrated that children with VH, particularly those with BVH, have poorer reading acuity scores than peers without VH regardless of hearing status. Furthermore, reading acuity scores correlated with dynamic and not static visual acuity scores. This might be due to difficulties with visual stabilisation (Braswell & Rine, 2006a). The effect of BVH on dynamic visual acuity in children with congenital or early acquired SNHL has not been established conclusively. While there is some research on the reading acuity of children with vestibular hypofunction (Braswell & Rine, 2006a), there still remain some areas that could do with better delineation, such as the effect of poor dynamic visual acuity on motor performance of children.

Most studies done on children with SNHL and VH focused on the motor performance of such children (Crowe & Horak, 1988; Horak et al., 1987; Rine et al., 2000). Only one study (Braswell & Rine, 2006a) investigated the effect of VH on visual acuity of children with SNHL. The relationship between reduced dynamic visual acuity and motor performance of children with SNHL has also not been established. Thus, in children with SNHL, the relationship between motor performance, dynamic visual acuity and BVH requires further definition, and research in this area could produce valuable information.

The purpose of the current study was to investigate the relationship between dynamic visual acuity, motor performance and vestibular function in children with SNHL, and to compare visual acuity, motor performance and vestibular function of children with SNHL to that of normal-hearing peers.

The tests that were used in the study will now be described briefly (a full description of the tests is included in Chapter 2). The Movement Assessment Battery for Children-2 (M-ABC-2) was used to evaluate motor skills. The M-ABC-2 is a norm-referenced test that was specifically developed for the identification and evaluation of children with mild to moderate motor impairment (Henderson et al., 2007). As it was established that there is an association between hearing loss and vestibular hypofunction and, in turn, reduced motor skills, it is to be expected that the group with SNHL will score poorer on the M-ABC-2 than normal-hearing peers (Angeli, 2003; Crowe & Horak, 1988; Horak et al., 1987; Rine et al., 2000).

A clinical test, the Southern California Postrotary Nystagmus Test (SCPNT), familiar to occupational therapists and physiotherapists was used in preference to electronystagmography (ENG) or videonystagmography (VNG) because the latter two are expensive and not readily available or accessible to therapists in South Africa. A clinical measure of vestibular function was obtained by means of a modified SCPNT (Ayres, 1989). This provides a standard procedure for measuring the duration of post-rotary nystagmus. However, the sensitivity and specificity of the SCPNT to determine VH has not been conclusively established.

The Dynamic Visual Acuity Test (DVA test) provides a clinical functional measure of the vestibular ocular reflex (VOR) (Longridge & Mallinson, 1987; Rine & Braswell, 2003). The subject reads a specially designed visual acuity chart with five symbols

on each line. Dynamic visual acuity is measured during self-generated or manually imposed head movements. Visual acuity was first determined with the head static and then repeated while the examiner manually moved the participant's head horizontally. A difference of more than two lines between static visual acuity (SVA) and dynamic visual acuity (DVA) indicates a significant decrease of visual acuity during head movement (Longridge & Mallinson, 1987; Rine & Braswell, 2003). As individuals with BVH have a deficient VOR, there is excessive movement of the image on the retina, leading to gaze instability. It was therefore expected that children with BVH would have a difference of more than two lines between the static visual acuity and the dynamic visual acuity scores (Rine & Braswell, 2003).

1.5 Research questions

Due to the close anatomical relationship between the cochlea and the vestibular system, children with congenital or early acquired SNHL might have reduced vestibular function, leading to motor difficulties and visiospatial problems (Angeli, 2003). Decreased dynamic visual acuity might be present only in individuals with BVH, because of impaired gaze stability (Rine & Braswell, 2003). It was expected that children with SNHL and reduced vestibular function will score poorer on the M-ABC-2 due to the dysfunctional vestibular spinal reflex (VSR). Although there are indications that motor development and VH may be related, little research has been done on the relationship between BVH and dynamic visual acuity in children with congenital or early acquired SNHL (Braswell & Rine 2006a). No previous studies could be found which examined the nature and extent of the relationship between motor performance, BVH and dynamic visual acuity in children with congenital or early acquired SNHL. Motor performance, vestibular function and dynamic visual acuity of the hearing-impaired group need to be compared to that of normal-hearing children to determine whether impaired motor performance, BVH and reduced DVA are associated with SNHL.

The research questions were therefore:

- what is the prevalence of impairments of motor performance, vestibular function and dynamic visual acuity, and
- what is the nature and extent of interaction between these in children with congenital and early acquired SNHL?

1.6 Aim and objectives

1.6.1 Aim

The aim of this study was to investigate the relationship between BVH, dynamic visual acuity and motor performance in children between the ages of 4 and 13 years old with congenital or early acquired SNHL. Children between the ages of 4 and 13 years old with congenital or early acquired SNHL, attending a South African inclusive, mainstream school for children with normal hearing and for children with a hearing loss, were included in the study. The children with the hearing loss were matched with a normal-hearing group from the same school according to age and gender.

1.6.2 Objectives

The specific objectives of the study were:

- To establish the inter-rater and intra-rater reliability of the SCPNT, DVA test and the M-ABC-2 as used in the research setting.
- To compare the prevalence of reduced intensity and duration of nystagmus (as induced by the modified SCPNT) and poor dynamic visual acuity (as determined by the DVA test) in children with SNHL with that in normal-hearing children, and to establish whether these phenomena are associated with SNHL.
- To investigate whether reduced intensity and duration of nystagmus (as induced by the modified SCPNT) are associated with poor dynamic visual acuity in SNHL.
- To investigate whether there is a significant difference in the scores on the M-ABC-2 between:
 - children with SNHL and children with normal hearing matched according to age and gender;
 - children with reduced intensity and duration of nystagmus and children with normal intensity and duration of nystagmus in the group with SNHL; and
 - children with poor dynamic visual acuity and children with normal dynamic visual acuity in the SNHL group.

- To establish which of the following are predictors of motor performance in children as determined by the M-ABC-2: intensity and duration of nystagmus, dynamic visual acuity, age, gender, the presence of SNHL.
- To establish which of the following are predictors of motor performance in children with SNHL: age, gender, degree of SNHL, presence of a cochlear implant, congenital/acquired SNHL, intensity and duration of nystagmus, dynamic visual acuity.

1.7 Significance of the study

As stated above, the relationship between BVH and dynamic visual acuity in children with SNHL has not been well researched. Problems with dynamic visual acuity may have an impact on learning to read, while difficulties with reading may influence scholastic performance (Braswell & Rine, 2006a). A finding that confirms that BVH is associated with decreased motor performance and reduced dynamic visual acuity would indicate the need for further research into the question whether vestibular rehabilitation therapy (VRT) could lead to improved motor and visual performance in children with SNHL. This, in turn, could have a positive impact on the education of children with SNHL. If no association is found, then this form of therapy would probably be unlikely to impact these impairments.

The role of the physiotherapist in the management of vestibular disorders is not well established in South Africa. The publication and presentation of the findings of this study to physiotherapy and other audiences would raise awareness of the possible role that physiotherapists could play in the management of vestibular disorders in children with SNHL.

1.8 Conclusion to introduction

Children with SNHL clearly experience functional limitations as a result of their hearing loss. Little is known about the effect of anatomical damage on vestibular function, which may also influence motor and visual functioning. The interrelationship between these deficits needs to be explored so that appropriate intervention, including physiotherapy treatment of motor and vestibular dysfunction, may be better informed.

2 LITERATURE REVIEW

2.1 Introduction

A computerised search was done on Pubmed, CINAHL and Medline. Keywords used were *vestibular hypofunction, acquired sensorineural hearing loss, congenital sensorineural hearing loss, conductive hearing loss, visual acuity, motor developmental milestones, cochlear implantation, vestibular function tests* and *vestibular rehabilitation*. In the literature review, the prevalence of SNHL and VH in children with SNHL, the anatomy, physiology, pathology and evaluation of the vestibular function, the visual system as well as the motor function is discussed.

2.2 Prevalence of SNHL and vestibular hypofunction in children

Northern and Downs (2001) devised a classification system to categorise the degree of hearing loss in children. A paediatric scale was developed due to the vastly different effect of hearing loss in children when compared to adults. In particular, congenital or early acquired hearing loss has a dramatic impact on learning spoken language. The classification system is as follows:

Pure tone average (PTA):	0 to 15 dB hearing loss:	within normal limits
	16 to 25 dB hearing loss:	slight
	26 to 30 dB hearing loss:	mild
	31 to 50 dB hearing loss:	moderate
	51 to 70 dB hearing loss:	severe
	71 + dB hearing loss:	profound

SNHL is the most common sensory deficit in children in developed countries (Smith, Bale & White, 2005). One child in 1 000 is born with bilateral congenital SNHL of at least 40 dB. This includes four profoundly (>90 dB) deaf infants per 10 000. Although definitive data regarding the prevalence of early onset hearing loss in the developing world are lacking it has been suggested that the rates are considerably higher than those in developed countries (Smith et al., 2005). While no large-scale study to determine the prevalence of hearing loss in South Africa could be found, it is postulated that the estimated prevalence of permanent bilateral infant hearing loss based on recently reported prevalence rates, is nine in every 1 000 babies (Swanepoel, Störbeck & Friedland, 2009). Nationally, an estimated 6 116 babies per

annum have congenital or early onset infant hearing loss (Swanepoel et al., 2009). Factors influencing the increased incidence of hearing loss in developing countries include the high burden of infectious disease, low socio-economic status and lack of education (Swanepoel et al., 2009). An example of an infectious disease implicated in SNHL, is meningitis, which is responsible for 6% of all cases of SNHL in children. Meningitis, and its associated hearing loss, strike early, with 75% of those afflicted being younger than two years of age. Infection spreads from the meninges to the labyrinth via the cochlear aquaduct and destroys the vestibular and cochlear hair cells resulting in vestibular loss and SNHL (Aneja & Aggarwal, 1997; Johnson, Hasenstab, Seicshnaydre & Williams, 1995). Bilateral SNHL as a result of meningitis is slightly more common than unilateral SNHL (Smith et al., 2005). It is reasonable to assume that children with profound SNHL due to bacterial meningitis may have BVH because of the transmission of the disease, and could be ataxic after the infection until compensation takes place.

2.3 Anatomy and physiology of the vestibular system

The vestibular system comprises three primary components: the peripheral sensory apparatus, the central vestibular system, and output of the motor neurons to the extraocular muscles, the skeletal muscles and the spinal cord (Hain & Helminski, 2007; Mehta & Stakiw, 2004).

2.3.1 The peripheral sensory apparatus

The peripheral sensory apparatus in the inner ear consists of two motion sensors: the three semicircular canals (SCC) and the otolith organs (the utricle and saccule) (Mehta & Stakiw, 2004). The SCC and otolith organs of the peripheral vestibular system have different functions. The vestibular-ocular system is responsible for visual stabilisation and clear vision during head movement and is mainly mediated by the SCC. The vestibular-spinal system contributes to the postural tone necessary for acquisition of motor developmental milestones and the maintenance of an upright stance and relies more on the input of the otolith organs than on the SCC (Angeli, 2003).

- **SCC**

The hair cells in the ampullae of the SCC convert mechanical energy to neural impulses that are relayed to the brainstem and cerebellum. The SCC detect angular

acceleration of the head. With head rotation, the endolymphatic flow in the canals causes deflection of the hair cells. The direction of deflection determines whether neural discharge will increase or decrease. With rotation of the head to the right, neural discharge of the hair cells will increase in the right horizontal SCC, whereas inhibition of the discharge rate of hair cells in the ampulla of the left horizontal SCC will occur (Hain & Helminski, 2007; Schubert & Minor, 2004). The hair cells of the SCC only respond to angular acceleration for the first seconds because the cupula returns to its resting position within a few seconds (Hain & Helminski, 2007).

The spatial arrangement that characterises the alignment of the three pairs of SCC is very important (Hain & Helminski, 2007). First, the plane of each canal is approximately perpendicular to the other canal planes. Second, the SCC on the one side of the head are influenced by the SCC on the other side of the head, and they form three coplanar pairs: (1) right and left horizontal, (2) left anterior and right posterior, and (3) left posterior and right anterior. When the one side of the pair is activated, the other side is inhibited. Third, the extraocular muscles are paired and oriented in planes similar to those of the SCC. This arrangement enables a single pair of canals to be connected mainly to a single pair of extraocular muscles. This results in conjugate movements of the eyes in the same plain as head motion (Hain & Helminski, 2007; Nandi & Luxon, 2008). Each pair of SCC is stimulated best by angular acceleration of the head in the plane of that pair of canals, e.g. the horizontal SCC are in the horizontal plane when the neck is in 30° of flexion and will be maximally stimulated with horizontal angular acceleration while the head is inclined by 30° (Hain & Helminski, 2007; Barber & Stockwell, 1980).

- Otoliths

The otoliths sense linear acceleration of the head. The hair cells in the medial wall of the saccule and floor of the utricle are deflected during linear acceleration. This mechanical deflection is converted into neural discharge and relayed to the brain stem and cerebellum. Horizontal linear acceleration and static head tilt lead to utricular excitation whereas vertical linear acceleration causes saccular excitation (Hain & Helminski, 2007; Schubert & Minor, 2004).

2.3.2 The central vestibular system

The primary vestibular afferents of the healthy vestibular system typically have a resting firing rate of 70 to 100 spikes per second. Cranial nerve VIII relays information regarding head movement from the peripheral sensory apparatus to the central vestibular system in the pons. This information is channelled simultaneously to the cerebellum and to the four vestibular nuclei in the pons. The superior and medial vestibular nuclei are the main nuclei of the VOR. The medial nucleus also plays a role in the VSR. Head and eye movements that occur together are coordinated by the medial nucleus. The lateral nucleus is the main relay for the VSR. The descending nucleus has no primary outflow of its own but is connected to all the other nuclei and the cerebellum. Input from the vestibular labyrinth is processed in association with somatosensory input and visual sensory input (Hain & Helminski, 2007). The cerebellum is a major recipient of impulses from the vestibular nuclear complex. The cerebellum is also a major source of input to the central vestibular system. Vestibular performance is monitored by the cerebellum and it readjusts central vestibular processing if necessary (Hain & Helminski, 2007).

2.3.3 The motor output

The motor neurons that are mainly affected by the output of the vestibular system are the motor neurons of the ocular motor nuclei which drive the extraocular muscles and the anterior horn cells of the spinal cord grey matter which, in turn, drive skeletal muscles. The motor output of the vestibular system is mediated by three vestibular reflexes: the vestibular-ocular reflex (VOR), the vestibular-spinal reflex (VSR), and the vestibular-collic reflex (VCR) (Hain & Helminski, 2007).

- **Output of the vestibular-ocular reflex**

The VOR enables the eyes to fixate on a target when the head is moving (Angeli, 2003). The VOR has two components: the angular VOR, mediated by the SCC, and the linear VOR, mediated by the otoliths (Hain & Helminski, 2007). The angular VOR is primarily responsible for gaze stability during angular head movements. In order to maintain gaze stability the image of an object is projected on the fovea of the retina. The VOR compensates for head movement by moving the eyes at a velocity equal to the velocity of the head but in an opposite direction to the head movement (Schubert & Minor, 2004). The ratio of eye velocity to head velocity is referred to as the *gain of the VOR*. To maintain gaze stability during head movements, the eye movement

must be of equal speed and amplitude but in the opposite direction to the head movement (Hain & Helminski, 2007). When VOR gain is poor, rapid eye movement – a corrective saccade – is produced when an error in the direction or amplitude of gaze with respect to the position of an object occurs. This brings the object onto the fovea in the shortest possible time (Fetter, 2007; Schubert & Minor, 2004). When the VOR gain is reduced, excessive motion of visual images across the retina of stationary objects will occur. This is referred to as *retinal slip* (Herdman & Whitney, 2007).

- Output of the vestibular-spinal reflex

The VSR is responsible for postural stability (Angeli, 2003; Nandi & Luxon, 2008). The VSR also plays a vital role in maintaining normal postural tone, which allows for the emergence of motor developmental milestones (Angeli, 2003). Vestibular impulses are transmitted to the motor neurons in the anterior horns of the spinal cord by way of the vestibulo-spinal tracts (Nandi & Luxon, 2008). The lateral vestibulo-spinal tract originates in the lateral vestibular nucleus. This tract carries input from the vestibular system and from specific areas of the cerebellum, and has a major influence on spinal motor activity (Shepard & Janky, 2008). The lateral vestibular tract receives contributions from every cell in the lateral nucleus. The lateral vestibular nucleus receives its input from the primary vestibular afferents of the VIIIth nerve, but also from cerebellar efferent fibres from the vermis and the fastigial nuclei. The spinal cord receives input throughout its entire length from the lateral vestibulo-spinal tract with the largest number of fibres in the cervical and lumbar segments. The other vestibulo-spinal tracts comprise of the medial vestibulo-spinal tract and the reticulo-spinal tract (Nandi & Luxon, 2008). The medial vestibulo-spinal tract originates in the medial vestibular nucleus, and the reticulo-spinal tract arises from the neurons of the bulbar reticular formation. Balance and coordinated movement are maintained by the integration of activities of the vestibular system, the cerebellum, the cortex and the reticular system through these pathways (Nandi & Luxon, 2008). The VSR has a much more complex task than the VOR. It can use multiple strategies to prevent falls. Limb motion needs to be adjusted appropriately by the VSR and the other motor pathways to compensate for the position of the head on the body. Additionally, in order to restore balance, one might plantar flex at the ankles, grab for support, take a step, or a combination of these strategies. The VSR

also relies to a greater extent on otolith input than the VOR (Hain & Helminski, 2007).

- Output of the vestibular-collic reflex

The VCR acts on the muscles of the neck in order to stabilise the head, especially during unpredictable movements (Nandi & Luxon, 2008). Movement sensed by the otoliths and the SCC is countered by reflex head movement. The precise pathways mediating this reflex are still unknown (Hain & Helminski, 2007).

2.4 Pathology of the vestibular system

Peripheral vestibular dysfunction involves the vestibular end organs and/or the vestibular nerves. Vestibular dysfunction can be unilateral or bilateral and can be congenital or acquired (Kaga, 1999; Schubert & Minor, 2004).

2.4.1 Causes of vestibular hypofunction

Peripheral vestibular dysfunction can be the result of several pathologies affecting the peripheral vestibular system. Bilateral vestibulopathy may be congenital or secondary to meningitis or due to vestibulotoxicity and chronic otitis media causing labyrinthitis.

- Congenital BVH could be the result of inner ear malformations (Casselbrandt & Mandel, 2005; Kaga, 1999). Some of these malformations affect only hearing, some only balance and some affect both hearing and balance. Children with BVH due to inner ear malformation usually experience poor balance and a delay in reaching gross motor developmental milestones (Kaga, 1999). However, by using visual cues and proprioceptive input, these children eventually reach their motor developmental milestones (Kaga et al., 2008).
- Ossification of the labyrinth as a result of bacterial meningitis can lead to SNHL and reduced vestibular function (Johnson et al., 1995). Meningitis can also lead to sequential neurological impairment resulting in central vestibulopathy (Johnson et al., 1995; Smith et al., 2005).
- Vestibulotoxicity results from the use of certain drugs, most commonly the aminoglycosides, such as gentamicin (Schubert & Minor, 2004). These drugs cause cellular degeneration of the cochlear and/or vestibular hair cells (Mehta

& Stakiw, 2004). The incidence of vestibulotoxicity in children is currently unknown (Mehta & Stakiw, 2004).

- Chronic otitis media with effusion is another common cause of acquired vestibular disorders in children (Casselbrandt, Villardo & Mandel, 2008; Mehta & Stakiw, 2004; Wiener-Vacher, 2008). The invasion of bacterial toxins in the inner ear can cause serous labyrinthitis and can lead to permanent high frequency SNHL (Mehta & Stakiw, 2004). It was reported that the vestibular function of children with a history of chronic otitis media with effusion was affected even in the absence of a concurrent episode of otitis media with effusion (Casselbrandt et al., 2008). It is possible that bacterial toxins may damage vestibular hair cells as well (Casselbrandt et al., 2008).

2.4.2 Pathology associated with SNHL

As mentioned in Chapter 1, VH is associated with SNHL. Pathologic changes in the cochlea, its receptors, or along the nerve pathway from the inner ear to the brain stem, result in SNHL (Northern & Downs, 2001). Due to the close anatomical relationship between the cochlea and the vestibular system, it has been hypothesised that damage to the vestibular structures is secondary to damage to the cochlea and by the same pathology that caused the hearing loss. VH may lead to delayed motor and balance development (Gayle & Pohlman, 1991; Nadol & Hsu, 1991; Rine et al., 2000).

- Iatrogenic factors associated treatment of SNHL

Cochlear implantation is regarded as a rehabilitative procedure to enable the recovery of sensorineural hearing in total or near-total hearing loss (Cushing, Papsin, Rutka, James & Gordon, 2008). During cochlear implantation, the lateral wall and fluid spaces of the cochlea are directly violated by the cochleostomy and the insertion of the electrode lead inside the scala tympani. There is a mixture of labyrinthine fluids due to the tearing of the basilar membrane by the electrode lead (Filipo et al., 2006). The vestibular structures are not directly violated by the surgery, but the presence of the implanted device within the inner ear fluid environment is likely to cause impairment (Cushing et al., 2008; Filipo et al., 2006). Damage to the vestibular structures due to surgery has been considered a worthwhile price to pay for the ability to hear sound after cochlear implantation (Cushing et al., 2008; Filipo et al., 2006). The ongoing electrical stimulation may also play an important role due

to the concomitant stimulation of both auditory and ectopic vestibular fibres (Cushing et al., 2008). For this reason, children with cochlear implants might be more likely to have vestibular deficits than children with no cochlear implants. It is however also possible that compensation can take place by using proprioceptive and visual cues (Kaga, 1999).

2.4.3 Symptoms and signs of vestibular dysfunction

Symptoms of VH arise from a mismatch of incoming signals from the three receptor groups (visual, vestibular and proprioceptive) that contribute towards balance and postural control (Schubert & Minor, 2004). The quality of vestibular symptoms depends on whether the lesion is uni- or bilateral (Tee & Chee, 2005).

Bilateral vestibular hypofunction is characterised by symptoms of gaze instability and oscillopsia and is most marked during head movement (Tee & Chee, 2005; Tusa, 2007). Gaze-holding mechanisms allow images to be maintained on the fovea of the retina and are essential for optimal visual acuity (Braswell & Rine, 2006a; Schubert & Minor, 2004). Normal ocular motor control is necessary for reading acuity (Braswell & Rine, 2006a). In individuals with VH, dynamic visual acuity and ocular motor control may be abnormal due to a VOR deficiency. VOR deficits may contribute to gaze instability during reading by disrupting the coupling of eye and head movement that is used for reading (Lee, 1999). Oscillopsia is reported by adults with BVH who complain of difficulty reading, particularly when upright and moving, e.g. reading road signs when driving (Grossman & Leigh, 1990). This visual blurring (oscillopsia) is worse with irregular or unpredictable head movements (Herdman & Clendaniel, 2007). Abnormal gain, abnormal phase shift between eye and head rotation (timing relationship for the eye and head position), and a directional mismatch between the vectors of the head rotation and eye rotation due to VOR deficits may lead to oscillopsia (Herdman & Clendaniel, 2007). The cause may be disease of either the vestibular periphery or its central connections (Herdman & Clendaniel, 2007). In the acute stage of BVH, patients may present with reduced visual acuity even when the patient is stationary and with the head not supported. Patients often complain that objects that are far away appear to be bouncing even after optimal compensation has taken place (Herdman & Clendaniel, 2007). In most severe cases, patients may even experience oscillopsia during chewing of food (Leigh, 2007).

Nystagmus is a sign of asymmetrical vestibular input and may be physiological or pathological (Whitney & Herdman, 2007). Nystagmus is the non-voluntary rhythmic oscillation of the eyes, and nystagmus of vestibular origin has clear fast and slow components beating in opposite directions (Honrubia, 2000; Polatajko, 1985; Schubert & Minor, 2004). The direction of the fast component defines the direction of the nystagmus (Polatajko, 1985). The slow component can be ascribed to the asymmetry between the tonic discharge rates of central vestibular neurons on each side (Honrubia, 2000). The fast component adjusts the eye movement and brings the eyes close to the centre of the oculomotor range (Honrubia, 2000).

Physiological nystagmus is the result of vestibular stimulation, visual or optokinetic stimulation or end-point nystagmus, which can occur on extreme lateral gaze (Schubert & Minor, 2004). Post-rotary nystagmus is an example of physiological nystagmus due to vestibular stimulation, which in turn is an indication of an intact VOR (Rine, 2007).

Lesions of the peripheral or central vestibular system as well as lesions of other CNS pathways can cause pathological nystagmus (Honrubia, 2000). This leads to the disruption of eye-movement control. Pathological nystagmus can be spontaneous, positional, gaze-evoked or congenital (Honrubia, 2000). Underlying pathology can be determined by the direction and intensity of pathological nystagmus and by the method used to induce nystagmus (Schubert & Minor, 2004).

So far, the literature review has outlined a variety of challenges faced by individuals with BVH. In particular, children with congenital or early onset acquired SNHL are suspected of having marked sequelae in terms of their motor development and dynamic visual acuity. Postural and gait disturbances are common signs of BVH (Horak, 2007). The vestibular system provides information about gravity and position of the head in space to the CNS. This information together with input from other sensory systems (visual and proprioceptive) is used to maintain posture and balance (Tee & Chee, 2005). With BVH, the patients have less vestibular input to rely on and present with balance and gait disturbances, such as walking with a wide base of support, and they become visually dependent (Tee & Chee, 2005). When visual cues or somatosensory inputs are decreased, these patients will experience more difficulty in maintaining balance (Tee & Chee, 2005). It was anticipated that the study

population would have postural instability and disturbed balance due to a deficient VSR.

Gaze instability caused by a reduced VOR gain results in reduced dynamic visual acuity (Braswell & Rine, 2006a). Braswell and Rine (2006a) hypothesised that the effect of BVH on reading is particularly relevant for young children who have BVH since birth or from shortly after birth, as it may interfere with learning to read due to gaze instability. It was anticipated that the study population would be likely to have decreased dynamic visual acuity due to the bilateral reduction of VOR causing gaze instability. It was unlikely that the current study population would perceive their symptoms as abnormal, because they have had it since birth or early childhood.

Because vestibular function plays such an important role in the acquisition of motor developmental milestones, education and quality of life of children (Kaga, 1999; Rine et al., 2000), it is crucial to evaluate the vestibular function of infants and children who are at risk of vestibular hypofunction. Several investigators have indicated that children with congenital or early acquired sensorineural hearing loss are at risk of having vestibular hypofunction because of the close relationship of the cochlea and vestibular labyrinth anatomically and phylogenetically (Crowe & Horak, 1988; Horak et al., 1987; Kaga et al., 2008; Selz, et al., 1996). As therapeutic techniques to address VH are available, evaluation of children at risk of vestibular impairment is necessary.

2.5 Evaluation of vestibular function

Vestibular function can be evaluated by means of clinical measures or laboratory measures (Schubert & Minor, 2004; Tusa, 2005). Tests for vestibular function evaluate the VOR as it is the most accessible output of the vestibular system (Angeli, 2003). Laboratory measures are impractical and expensive in a developing country like South Africa (Rogers, personal communication, 6 October 2009). In this study, two clinical measures for vestibular function were used, namely the Southern California Postrotary Nystagmus Test (SCPNT) and the clinical Dynamic Visual Acuity (DVA) test. These two tests are discussed in detail, while other clinical measures are discussed briefly. Laboratory measures to measure VOR include electronystagmography, caloric testing and rotary chair testing. These tests were not

used in the current study and are therefore not included here. A description of these tests can be found in Appendix A.

2.5.1 Clinical measures of the VOR

When vestibular function is evaluated clinically, a careful history is necessary (Schubert & Minor, 2004; Tusa, 2005). Clinical measures involve the assessment of eye movements, posture and gait (Tusa, 2005). The examination of eye movements can be of great importance in defining and localising vestibular pathology due to the direct relationship between the receptors of the inner ear and eye movements produced by the VOR (Schubert & Minor, 2004).

- **Head thrust test**

The head thrust test is used to evaluate horizontal SCC function (Schubert & Minor, 2004). To obtain maximal stimulation of the horizontal SCC, the neck is flexed 30° (Schubert, Tusa, Grine & Herdman, 2004). While the patient tries to focus with the eyes on a stationary target, the head is manually rotated in unpredictable directions. A small amplitude (5°–15°) and high acceleration (3000-4000°/s²) angular head thrust is performed. With normal vestibular function, the VOR will move the eyes in the opposite direction than the head movement and through the exact angle required to keep the image stable on the fovea. With VH, the eyes move less than required and the eyes leave the target. A corrective saccade follows to bring the image of the target back onto the fovea. Corrective saccades occur with angular rotation towards the side of the hypofunction because inhibition of vestibular afferents and central vestibular neurons on the intact side (inhibitory cut-off) is less effective than excitation in encoding the amplitude of a head movement. The head thrust test is sensitive when indicating a complete loss of vestibular function, but less sensitive with an incomplete loss (Schubert & Minor, 2004; Schubert et al., 2004). Using caloric irrigation as gold standard, the sensitivity and specificity are 100% for complete unilateral vestibular loss due to nerve section (Foster, Foster, Spindler & Harris, 1994; Halmagyi & Curthoys, 1988). When the head thrust test is compared with caloric irrigation in patients with an incomplete unilateral loss, the sensitivity is 36% and the specificity 97% (Foster et al., 1994; Harvey & Wood, 1996). According to the literature (Crowe & Horak, 1988; Horak et al., 1987), vestibular function in children with SNHL can range from normal function to complete loss bilaterally. It

was therefore assumed that vestibular function of participants in the current study would possibly range between normal function and a complete loss bilaterally. Although the head thrust test is accessible and affordable in a developing country context, it was not utilised in the current study because of its low sensitivity (36%) for incomplete unilateral loss.

- **Head-shaking-induced nystagmus**

The head-shaking-induced nystagmus (HSN) test is a diagnostic tool to indicate asymmetrical vestibular input to the central vestibular regions (Schubert & Minor, 2004; Tusa, 2005). During the performance of the HSN test, the subject's vision needs to be obstructed to prevent fixation on a visual target. Visual fixation can suppress nystagmus. The neck needs to be flexed 30° to get optimal stimulation of the horizontal SCC. The head is then manually oscillated horizontally for 20 cycles at a frequency of 2 Hz (2 cycles per second). After the 20 cycles are completed, the subject should open his/her eyes and the eyes will be observed for any nystagmus. With symmetric peripheral vestibular input, no nystagmus will be generated. With UVH, a burst of nystagmus will result with the quick component towards the intact side (Schubert & Minor, 2004; Tusa, 2005). Compared to caloric testing, the sensitivity of the head-shaking-induced nystagmus test is 46% and the specificity, 75% (Takahashi, Fetter, Koenig & Dichgans, 1990; Wei, Hain & Proctor, 1989). This test is however not sensitive for complete vestibular loss bilaterally because there is no asymmetry in the tonic firing rates (Schubert & Minor, 2004). For this reason, the test was not suitable for this research study.

- **Dynamic visual acuity test**

Visual acuity is measured by the dynamic visual acuity (DVA) test during self-generated or manually imposed head movements. Computerised as well as clinical versions of the test are available (Schubert & Minor, 2004). The clinical DVA test provides a clinical functional measure of the VOR. The DVA test was originally described by Longridge and Mallinson (1987) as the Dynamic Illegible E-test. The test measures visual acuity with the head held still while the subject reads a specially designed visual acuity chart of E's. The test is then repeated and visual acuity is measured during horizontal or vertical sinusoidal head movements. The change in acuity is then recorded (Longridge & Mallinson, 1987). The Illegible E-test examines the VOR by evaluating the ability of the eyes to focus on a stationary target while the

head is moving from side to side (Longridge & Mallinson, 1987; Nandi & Luxon, 2008). To isolate the vestibular contribution to gaze stabilisation horizontal or vertical sinusoidal head movements are performed at 2Hz and peak head velocities greater than 120° per second, which exceeds the capabilities of the visual system (Longridge & Mallinson, 1987). Longridge and Mallinson (1987) compared the results of their Dynamic Illegible E-test with caloric responses. They found a significant relationship between gradual deterioration of results on the Dynamic Illegible E-test score and progressive worsening of caloric responses ($p < 0.05$) (Longridge & Mallinson, 1987).

The DVA test that was adapted by Rine and Braswell (2003) for use with young children will be described in detail. The Lea vision chart by Lighthouse Low Vision Products was used instead of the letter E or Snellen chart that is generally used for testing adults. The Lea vision chart has symbols instead of letters. It has five symbols on each line (square, circle, house and apple). Visual acuity is typically expressed as log MAR or the logarithm of the minimum angle of resolution (MAR). Each line of the vision chart contains a symbol of a size that is the \log_{10} of the angular subtense of the stroke widths at the distance from which the chart was designed to be read. Each line corresponds with a log MAR value. Between each two lines there is a change in acuity of 0.1 log MAR. Acuity doubles every third line. The subject is seated 3 m from the chart on a chair. The chart is placed at eye level and the subject is asked to identify the symbols with the head stationary. The log MAR value of the line where the subject misses three symbols is recorded. The log MAR value of the line where the subject has no mistakes is also recorded. The test is then repeated with the neck in 30° flexion and passively rotated 15° from the centre to the left and right at a frequency of 2 Hz. A dynamic visual acuity score is then calculated as the difference between static visual acuity (SVA) and dynamic visual acuity (DVA) in lines using the following formula (Rine & Braswell, 2003):

$$\text{DVA score} = \text{abs} [(\text{SVA log MAR} \times 10)] - [(\text{DVA log MAR} \times 10)]$$

If visual acuity deteriorates with more than two lines on the Lea vision chart, it is an indication of gaze instability most likely due to a vestibular defect (Rine & Braswell, 2003). The test-retest reliability for SVA and horizontal DVA (hDVA) was found to be excellent with ICC=0.94 and 0.84, respectively, as well as the inter-rater reliability with ICC for SVA=0.93 and for horizontal DVA=0.88 (Rine & Braswell, 2003).

Sensitivity, specificity, positive and negative predictive values for BVH were 100%, regardless of age (ANOVA $p=0.007$) (Rine & Braswell, 2003). This test demonstrates a reliable and valid test for gaze stability and is excellent for screening for VH in children as young as 3 years of age (Rine & Braswell, 2003). This test was regarded the most appropriate test for this study because it is a measure of the VOR and it provides an indication of gaze stability. When compared to the head-shaking test and head thrust test the DVA test is more sensitive for incomplete loss than the head thrust test and more sensitive to complete bilateral vestibular loss than the head-shaking test. The DVA test is also an affordable test and suitable in a developing country context.

- **Rotational tests**

During rotation of a patient along the vertical axis, the horizontal SCC and vestibular nerve endings are stimulated. This leads to physiological nystagmus in patients with normal vestibular function (Schubert & Minor, 2004). The Southern California Postrotary Nystagmus Test (SCPNT) is a rotational test that was described by Ayres (1989). It provides a standard procedure for measuring post-rotary nystagmus (Ayres, 1989). The child sits cross-legged on a board that can rotate freely. The SCPNT is performed in the light with the subject's eyes open. The board is rotated ten times at a speed of 1 Hz to one side. The board is then stopped suddenly. The number of beats, excursion and duration of nystagmus is visually observed by the examiner. After two minutes, the test is repeated to the other side to evaluate the opposite labyrinth. This test is a measure of how quickly the VOR can be suppressed by light. In the SCPNT, normal duration of nystagmus is between 8 and 12 seconds (Ayres, 1989). In children with VH, there will be either no nystagmus or just a few beats lasting less than 7–8 seconds (Ayres, 1989; Rine et al., 2000).

The clinical test to provide a vestibular stimulus in the case of this study was a modified version of the SCPNT. Fixation was prevented in the current study by the use of Frenzel lenses and the test was done in the dark. This modification was utilised to make the SCPNT similar to laboratory rotary chair testing, which is performed in the dark and measures the VOR. The modified SCPNT was chosen for use in the current study because it gives an indication of the responsiveness of the horizontal SCC and is a measure of the VOR. The modified SCPNT is also less invasive than the ENG/VNG and caloric testing. Rotation is furthermore a

physiological stimulation of the vestibular system and enjoyable for most children. It is easy to perform in the clinic, inexpensive and safe to use with children (Royeen, 1980).

The validity of the SCPNT has not been established conclusively. Keating (1979) compared the results obtained in the SCPNT with the results of ENG and caloric testing. Twenty normal female adults, four girls with normal learning abilities with a mean age of seven years and three months, and four girls with learning disabilities with a mean age of eight years and one month participated in this study. None of the participants had been diagnosed with central nervous system damage or hearing loss, or had a history of seizures. The results were as follows. There was a significant correlation between the duration of nystagmus as measured by the SCPNT and the duration of nystagmus as measured by the ENG in the adult group. The Pearson product-moment correlation was used and results showed a correlation of 0.899, $p < 0.01$. Correlations coefficients of 0.1, 0.3 and 0.5 are interpreted as small, medium and large respectively (Green & Salkind, 2008). There was also a significant correlation between the two tests in terms of duration of nystagmus but not in terms of excursion in the group of normal girls. Maximum excursion of the eye was estimated by visual observation. The Spearman rank-order correlation was used to correlate the duration and excursion of nystagmus as measured by the two tests. The correlation between the two tests in terms of duration was 0.949, $p < .05$, but the correlation in terms of excursion was not significant. In girls with learning disabilities, there was no significant correlation between the two tests. Excursion of nystagmus seems more difficult to monitor (Keating, 1979). The SCPNT might not be suitable for children with learning disabilities (Keating, 1979). Learning-disabled children often demonstrate a short attention span and difficulty in following instructions that may have an impact on test results (Keating, 1979). It is possible that children with learning disabilities could have been more likely to inhibit nystagmus if they could not understand instructions not to do so than children with normal learning abilities.

Nelson et al. (1984) compared the results of the visually monitored SCPNT and an ENG-monitored SCPNT under three conditions of illumination – bright, dim and dark. Comparison of visually monitored and ENG-monitored duration, frequency and excursion of post-rotary nystagmus was only possible under bright and dim conditions because the room remained dark for two minutes after the rotations in the

dark to allow for the maximum amount of time during which ENG recordings were made. There was no difference between visually monitored duration of post-rotary nystagmus under bright and dim conditions $t(17) < 1.0$. However, a substantial difference was observed between responses in light and completely dark conditions in ENG-recorded duration of nystagmus, indicating that duration of nystagmus in dark conditions was significantly longer ($p < 0.01$) than in light conditions. Pearson product-moment correlations were used to determine concurrent validity of the SCPNT duration of nystagmus and ENG duration of nystagmus. The correlations between scores on the SCPNT and the ENG under bright conditions were significant $r = 0.75$ ($p < 0.01$), while under dim conditions, the correlation was $r = 0.56$. The authors were surprised that these were not higher. The reason for the difference in duration of post-rotary nystagmus under dark and light conditions might be that the subject was unable to fixate in dark conditions. This study demonstrated the importance of preventing fixation when determining the duration of nystagmus. Due to the influence of the cerebellum, vestibular nystagmus can be inhibited (Hain & Helminsky, 2007). If the subject is able to fixate, it will reduce or possibly abolish the presence of nystagmus. With the ENG, it is possible to do the test with the eyes closed or with the eyes open in complete darkness to prevent fixation while the nystagmus is being recorded. For the current study, every effort was made to prevent fixation during and after rotations. Frenzel lenses were used during and after rotations, and the test was done in a dark room to prevent fixation. Frenzel lenses are 20-diopter lenses that can be used to block visual fixation. The focal length is several centimetres. The advantage is that these lenses allow observation of nystagmus by magnifying the image of the eyes (Levy et al., 1997). It also reveals nystagmus, which may otherwise be suppressed by fixation (Honrubia, 2000; Levy et al., 1977).

Several studies have been carried out to investigate the test-retest reliability of the SCPNT. A study to determine the reliability of the SCPNT in children with learning disabilities was done by Morrison and Sublett (1983). They found that duration of post-rotary nystagmus was significantly depressed in children with learning disabilities, and that these children also exhibited a wider range of scores than children without learning disabilities. They found that inter-rater and intra-rater reliability was significant for learning disabled children ($r = 0.72$, $p = 0.000$ and $r = 0.67$, $p = 0.000$ respectively), but it was lower than what was established for children

without learning disabilities. Restlessness, distractibility and inappropriate social behaviour were suggested as reasons that could affect the scores of children with learning disabilities. It is therefore important to encourage children to co-operate and also to allow periods of rest when needed to ensure that the children can concentrate on the procedure.

Royeen (1980) did a pilot study with primary-grade children to determine whether time of day or gender affected the test-retest reliability. Twelve boys and twelve girls participated in Royeen's study. Participants were tested in the morning and were then retested two weeks later. Half of the participants were tested at the same time of the day as the first test and the other half was tested at a different time in the afternoon. Royeen found that the reliability coefficient was not affected by the gender of the child or the time of day of the test. The retest reliability was found to be above 0.8 for all conditions which can be regarded as high (Green & Salkind, 2008). It was unusual for participants to show alarm or loss of balance while rotating. This finding is an indication that the SCPNT is a low-risk test and therefore suitable for children who are regarded as a vulnerable research population.

Kimball (1981) retested 63 healthy children two and a half years after the initial testing and found a test-retest reliability coefficient of 0.80. This indicates that the SCPNT is stable for normal subjects. In contrast, Deitz, Crowe and Siegner (1981) reported weak test-retest reliability for three-year-olds but adequate test-retest reliability for four-year-olds. They questioned the use of the SCPNT in three-year-old children. In the current study, only children aged four years and older were tested.

The reliability of the SCPNT has not been established for children with congenital or early acquired SNHL and needed to be established in the current research setting. In the light of the above discussion and due to the fact that quantitative vestibular function tests are not readily available in South Africa – except for caloric irrigation which is not tolerated very well by young children and is expensive – it was decided to investigate the utility of the SCPNT in a developing country context.

2.6 Assessment of motor system function

There are several tests designed to assess motor performance in children, and an overview of these is given in Appendix B. Assessments like the Peabody Developmental Motor Scales-2 (PDMS-2) and the Miller Assessment for

Preschoolers (MAP) were not appropriate because of the age of the subjects. The Brief Assessment of Motor Function (BAMF) and the Pediatric Evaluation of Disability Inventory (PEDI) assess the functional ability of children with significant neuromotor dysfunction (Hayley, Coster, Ludlow, Haltwanger & Andrello, 1992). These tests were not used in the current study because the study population was not expected to show any outward signs of motor incompetency. The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) was not used because there is some evidence that the BOTMP lacks a sound psychometric foundation for the aggregation of the subtest scores to produce a single battery composite score (Hattie & Edwards, 1987). The test used for motor proficiency was the Movement Assessment Battery for Children-2 (M-ABC-2), which will be discussed in detail in 2.6.1.

2.6.1 The Movement Assessment Battery for Children-2 (M-ABC-2)

The M-ABC-2 was used to evaluate motor skills in this study. The M-ABC-2 is a norm-referenced test that was specifically developed for the identification and evaluation of children with mild to moderate motor impairment (Henderson et al., 2007). It is divided into three age bands for age groups between 4 and 16 years, each of which contains eight motor items that are placed into three categories: manual dexterity, ball skills, and static and dynamic balance (Henderson et al., 2007). The items are different for each age group but cover similar skills. The different age bands are discussed in detail in Appendix C. The scores on the individual items range from 0 to 5 and are ordinal. High scores attained on an individual item indicate a greater degree of difficulty with the item. The sum of the individual scores on the eight motor items provides a total impairment score. The item scores do not differentiate between children performing better than the 25th percentile of the standardisation group (Van Waelvelde, De Weerd, De Cock & Smits-Engelsman, 2004). This however did not influence the validity of the instrument for this study because the instrument was to identify motor impairment and not optimal functioning.

The M-ABC-2 was standardised simultaneously in the UK and Canada with approximately 600 children in each country, and is considered to be a valid and reliable test of motor impairment (Junaid & Fellowes, 2006). Reliability and validity were also established in Belgium (Van Waelvelde, Peersman, Lenoir & Smits-

Engelsman, 2006) and the Netherlands (Smits-Engelsman, Henderson & Michels, 1998). A study in Sweden suggested a good correspondence between the performance of Swedish and American children on AB1 of the M-ABC-2 (Rösblad & Gard, 1998). The intra-class correlations (ICC) for inter-rater reliability for the M-ABC-2 exceeded 0.95 and ranged between 0.92 and 0.98 for the test-retest reliability (Chow & Henderson, 2003).

The M-ABC-2 was chosen for use in this study because it is valid and reliable for the age group 4 to 16 years and it is quick and easy to execute. The three different components are specific to whether a child has problems with fine motor skills, ball skills, or static or dynamic balance. It is also adequately responsive to identify mild motor impairment.

2.7 Studies on motor performance, vestibular function and visual acuity in children with SNHL

Prevalence and intervention studies of vestibular dysfunction in children with SNHL will be discussed in this section.

2.7.1 Prevalence studies of vestibular dysfunction in children with SNHL

Several authors have shown that children with SNHL also present with motor deficits (Crowe & Horak, 1988; Horak et al., 1987; Rine et al., 2000). Since the 1950s, a number of studies have been performed with the aim of establishing the prevalence of vestibular dysfunction in hearing-impaired populations. According to Rosenbult, Goldstein and Landau (1960), 49% of 107 children with congenital and acquired hearing loss in their study had depressed caloric-induced nystagmus. It is however not clear whether those participants had SNHL or conductive hearing loss. Arnvig (1955) in his study found that 82% of the 89 participating children with severe acquired hearing loss resulting from meningitis, measles or encephalitis and 34% of 129 children with congenital hearing loss had abnormal responses to vestibular tests. From this study, it seems that children with acquired SNHL are more likely than children with congenital SNHL to have vestibular involvement as well. These investigators used caloric testing to determine vestibular function. The caloric test only tests the function of the horizontal SCC with the result that the anterior and posterior SCC functions are not evaluated. The difference in the results of the abovementioned two studies is probably due to the fact that Rosenbult et al. (1960)

included in their study subjects with hearing loss of mixed aetiologies in the same group, while Arnvig (1955) reported on congenital and acquired hearing loss separately. It seems that the aetiology of hearing loss plays an important role in the prevalence of VH in children with SNHL.

More recently, several researchers conducted studies of the vestibular function of children with SNHL. Crowe and Horak (1988) investigated the relationship between vestibular function and motor proficiency in children with hearing loss between the ages of seven and thirteen years old. Two groups of children were evaluated. The first group consisted of 13 children with no hearing loss. The selection of the normal-hearing group was based on convenience. The second group comprised 29 children with hearing impairments. The hearing threshold of this group was above 30 dB in both ears. Nine children had hearing loss as a result of meningitis, one child had had rubella and four children had congenital hearing loss. The cause of hearing loss in the remaining 15 children was unknown. Tests performed included rotary chair and posturography, which evaluates sensory organisation deficits. Motor proficiency was tested by evaluating balance, muscle tone and coordination. Different examiners were used to do the different tests. Examiners were blinded to the results obtained by other examiners. They found that 24% of children with hearing loss in their study had normal vestibular function and normal motor proficiency. A total of 66% of the children with hearing impairment in the study of Crowe and Horak (1988) had loss of peripheral vestibular function and normal motor skills except for the reduced ability to maintain balance. Ten percent of the hearing-impaired children with sensory organisation deficits had more widespread motor difficulties. Crowe and Horak (1988) concluded that motor proficiency in children with hearing impairments depends on vestibular function. Due to the small sample size, the results of this study cannot be generalised to the whole population with hearing loss. It is not specified whether the hearing loss of the 15 children with unknown aetiology was SNHL or conductive hearing loss. The type of hearing loss might have had an effect on the degree of vestibular impairment and whether it is transient or permanent.

Horak et al. (1987) compared the vestibular status and motor proficiency of 30 hearing-impaired children and 15 motor-impaired learning disabled children with 54 normally developing seven- to twelve-year-olds. Similar to the study by Crowe and Horak (1988), this study also used rotary chair testing to determine vestibular

function and posturography to evaluate sensory organisation. Motor performance was evaluated by the administration of the gross-motor subtests of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP). The subtests included balance activities, running speed, bilateral coordination and strength. Crowe and Horak (1988) found reduced or absent vestibular function in 20 of the 30 hearing-impaired children in their study. However, they concluded that VH did not affect the development of motor proficiency except for balance activities. Balance activities included activities in standing, which is dependent on vestibular function. When the participants were forced to rely on vestibular input only and when visual and proprioceptive input was unreliable, they could not maintain balance. VH caused fallout on the posturography tests where the use of vestibular input for postural control is required. Widespread motor deficits were associated with sensory organisation deficits in the learning disabled group and in three children of the hearing-impaired group. It seems that children with loss of peripheral vestibular function early in life compensate for their loss by relying on visual cues or supporting surface input when it is available. Due to the small sample size, the results of this study cannot be generalised to the whole population with hearing loss or learning disabilities.

Selz et al. (1996) tested three groups of children between the ages of eight and 17 years. Each group consisted of three boys and two girls. The control group had no history of hearing loss or balance impairment. The two experimental groups consisted of five children with congenital SNHL and five children with early acquired (before the age of two years) hearing loss due to meningitis. Each child underwent eye tracking, positional and positioning testing and rotary chair testing. Significant differences were found in gaze nystagmus between both deaf groups and also between the deaf groups and the normal-hearing group. An increase of gaze nystagmus is an indication of pathology in the central pathways. Both deaf groups showed reduced vestibular function. Children with congenital hearing loss showed reduced vestibular function to a lesser degree than the group with acquired hearing loss. As meningitis is a diffuse inflammatory disease, it can affect all areas of the central nervous system (Aneja & Aggarwal, 1997). This can be an indication that the factor that has damaged the cochlea and caused the hearing loss could also affect

the peripheral vestibular system. This can however not be generalised due to the small sample size.

Rine and Brasswell (2003) tested eleven children with bilateral severe or profound SNHL. The VOR was tested by means of rotary chair testing in total darkness. Electro-oculography was used to record eye movements. Dynamic visual acuity was tested by the Lea vision chart by Lighthouse Low Vision Products. Results revealed that children with SNHL and BVH as indicated by rotary chair testing had DVA scores during horizontal head movements that were significantly greater than those of peers with SNHL but without VH, suggesting that children with BVH had marked gaze instability as they could not use the VOR cues to stabilise the image on the fovea during head movement. The rotary chair test demonstrated bilaterally reduced vestibular function, and the DVA test indicated that gaze instability is present. These findings suggest that BVH in children with SNHL leads to problems with dynamic visual acuity, which might indicate the need to test children with SNHL for VH as it may impact on their education and quality of life (Mehta & Stakiw, 2004). However, the sample size of this study was small and results cannot be generalised to the whole population with SNHL.

Braswell and Rine (2006a) showed that reading acuity of children was significantly worse in children with SNHL and VH. They evaluated the reading acuity and gaze stability of fourteen children with SNHL with or without vestibular hypofunction. Reading acuity was tested by means of the Paediatric reading acuity test and gaze stability by means of the DVA test. They found that children with VH, particularly children with BVH, had significantly poorer reading acuity scores and reading acuity scores correlated with dynamic and not static visual acuity scores. They argued that the gaze instability is responsible for poorer reading acuity scores in children with VH. Although the sample size was too small to generalise these results, it may indicate the need to evaluate children with SNHL for VH. Reading acuity of children with SNHL and VH, especially those with BVH, should also be evaluated, so that appropriate therapy can be provided.

Kaga (1999) investigated whether vestibular compensation takes place during development of children with VH. Longitudinal studies were done with children and infants with congenital and early acquired abnormalities of vestibular function. Rotational testing was done to determine vestibular function. He found that gross

motor function and balance were significantly delayed in these children during the first two to three years of life. During the pre-school years, all children achieved most motor developmental milestones such as head control, independent walking and running. Balance, however, was still impaired in all children with VH at six years of age. Improved motor skills probably depend on the integration of the compensatory input from visual, somatosensory and proprioceptive systems, as well as maturation of the motor control system. Static balance without visual input was impossible in this study, probably due to the fact that the children had to rely on vestibular input, which was absent or inadequate.

Kaga et al. (2008) evaluated 11 boys and 9 girls with profound congenital hearing loss between the ages of 31 and 97 months prior to cochlear implantation. Vestibular function was tested by means of the ice-water caloric test, rotary chair test and vestibular evoked myogenic potentials (VEMP), which is a measure of the function of the saccule (Schubert & Minor, 2004). The ice-water caloric test is a much stronger test stimulus than the usual test protocol. Fifteen percent of the children so tested had normal responses on the ice-water caloric test, rotary chair test and VEMP bilaterally. Thirty-five percent showed asymmetrical responses on the caloric test but normal responses in the rotary chair test and VEMP bilaterally. Twenty-five percent presented with reduced responses on the caloric test bilaterally and normal responses in the rotary chair test and with normal reproducible or decreased VEMPs. The rest of the group (25%) had no reaction to the caloric tests, the rotary chair test or the VEMP recording. Eighty-five percent of the children demonstrated abnormal results in at least one test. Fifty percent of the children showed reduced function with the ice-water caloric test. According to this study, 70% of children showed normal reactions to rotary chair testing. This is slightly higher than the results of studies by Horak and Crowe (1988) and Horak et al. (1987). This might be due to different test frequencies during rotary chair testing. The authors argued that the rotary chair testing stimulates hair cells in both ears simultaneously whereas the ice-water caloric test only stimulates the horizontal canal of one ear at a time at low frequency resulting in 35% with abnormalities with ice-water caloric testing. The VEMP test stimulates the saccule to determine saccular function. Fifty percent of the children in the study group showed normal bilateral function, 30% of the children demonstrated asymmetrical function and 20% showed no response. These authors'

findings suggest that, in spite of a case battery of tests having been used, no one test can give a complete assessment of vestibular function. A summary of the abovementioned studies is displayed in Table 1.

Table 1: Summary of research findings of prevalence studies of VH in children with SNHL

Authors and year	Sample size and participant description	Tests done	Results in children with SNHL	Results in normal-hearing children	Comments
Crowe & Horak, 1988	13 normal-hearing (NH) children, 29 hearing-impaired (HI)	Rotary chair (ROTO), dynamic posturography (DP), motor proficiency (MP)	If reduced vestibular function, also reduced balance	Normal vestibular function, normal MP	Balance is more affected than other motor skills and associated with VH
Horak et al., 1987	30 HI, 15 motor impaired, 54 normal developing	MP, ROTO, DP	Reduced/absent vestibular function. Reduced balance.	Normal vestibular function, normal MP	Children compensate for reduced vestibular function by using visual and somato-sensory cues.
Selz et al., 1996	Five children with NH and normal balance, 5 congenital SNHL, 5 early acquired SNHL	ROTO, eye tracking, positional and positioning testing	Congenital SNHL had VH to lesser degree than acquired SNHL.	Normal vestibular function	Small sample size. Type of SNHL affects vestibular function.
Braswell & Rine, 2006a	Fourteen SNHL with/without VH; 72 normal developing children	Paediatric reading acuity test.	Children with VH scored poorer on reading acuity. Reading acuity correlated with VH	Normal reading acuity.	Small sample size. Important to test reading/visual acuity in children with VH.
Kaga, 1999	Longitudinal case studies	Motor development test, balance, ROTO, calorics.	Motor development milestones reached by adolescence.		Compensate by using somato sensory and visual systems.

The abovementioned studies showed that vestibular function may be compromised when associated with SNHL in childhood. Some of these studies (Crowe & Horak, 1988; Horak et al., 1987; Rine et al., 2000) also suggested that VH is, in turn, associated with problems with motor proficiency and delayed motor development milestones. Oscillopsia is a common complaint of adults with bilateral vestibular hypofunction, and these adults have difficulty with reading due to visual instability (Tee & Chee, 2005). It is therefore reasonable to expect that children with SNHL and BVH may have problems with visual stabilisation and dynamic visual acuity, which, in turn, can lead to reading difficulties (Braswell & Rine, 2006a). This can have an impact on the education and quality of life of these children as well as their future earning potential.

In summary, although it appears that impairments of vestibular, visual and motor function appear to be associated with SNHL, there seems to be a paucity of literature relating to the prevalence of reduced dynamic visual acuity and the interaction between these impairments.

2.7.2 Intervention studies of children with SNHL and associated VH

Rine et al. (2004) randomly assigned 21 children with SNHL and vestibular impairment to two groups. The groups were matched for age and gross motor development level. One group received balance training and exercises focusing on visual and somatosensory function. In the second group (control), the emphasis was on language development. Each intervention was done three times a week for twelve weeks. The examiners completing postural control and motor development testing were blinded as to group placement. Motor development was tested using the gross motor scale of the PDMS. Motor development and posturography were evaluated before and after intervention in both groups. Motor development scores significantly improved in the exercise group and not in the control group. There was also improvement in the posturography scores of the exercise group, but it was not significant. The control group received exercise intervention after the post-test and a second post-test was done after the intervention. The control group also showed a significant improvement after exercise intervention. This study indicated that exercise intervention focusing on sensory integration and balance is effective for the improvement of motor developmental skills. It is therefore necessary for children with

SNHL and VH to receive appropriate intervention to address the developmental delay in these children.

Braswell and Rine (2006b) also published a case report on a study where two children with SNHL and VH received visual-vestibular exercises. They found that the child with acquired SNHL and VH showed significant improvement of DVA scores but not the child with congenital SNHL and VH. There was improvement of the critical print size and reading acuity in both subjects after intervention. This is however not a large-scale study with enough participants to make results significant. No other studies with a larger sample size could be found where the DVA score, reading acuity and critical print size were evaluated after visual-vestibular exercises in children with SNHL and VH. It seems that the effect of visual-vestibular exercises on dynamic visual acuity and reading acuity has not been researched extensively, and more research is needed to develop this underexplored area.

Table 2: Summary of research findings of intervention studies in children with SNHL and VH

Authors and year	Sample size	Tests done	Results in children with SNHL	Comments
Rine et al., 2004	21 SNHL and VH, divided into 2 groups	Posturography and motor development	Motor development improved after balance training	Intervention necessary to improve motor proficiency
Braswell & Rine, 2006b	2 children, 1 with congenital SNHL and VH, 1 with acquired SNHL and VH	DVA, reading acuity, critical print size	Child with acquired SNHL and VH showed significant improvement of DVA. Child with congenital SNHL and VH showed no significant improvement of DVA	Case study is weakest form of data collection

2.8 Conclusion

The most appropriate instrument for measuring motor performance appeared to be the M-ABC-2. Although there are concerns about the SCPNT in terms of its ability to evaluate vestibular hypofunction, it was used in the current study due to its availability, accessibility and affordability, all key components of the primary health care approach which the South African government has adopted (Magnussen, Ehiri & Jolly, 2004). Instrument- and technology-dependent tests of vestibular function are not readily available in South Africa and this poses challenges in terms of their application, interpretation and suitability for the paediatric population (Bakr, Ezzat & Saleh, 2000; Barber & Stockwell, 1980; Cyr, Brookhouser, Valente & Grossman, 1985). The clinical DVA test, on the other hand, is a feasible test due to the minimum of equipment required. It is also a reliable and valid test to evaluate visual acuity during head movements and was therefore adopted for this study (Rine & Braswell, 2003).

3 METHODOLOGY

3.1 Research design

The current research utilised a quantitative, correlational, cross-sectional, descriptive design. A cross-sectional descriptive study aims to describe phenomena at a certain point in time (Durrheim, 2006). The intention of the study was to describe the relationship between motor performance, visual acuity and vestibular function in children with SNHL at a specific point in time.

3.2 Hypotheses

Different hypotheses were tested regarding the prevalence of and the relationship between the different impairments in children with SNHL. The primary hypothesis was that motor ability is not predicted by dynamic visual acuity and VH. The following null (H_0) and alternate (H_1) hypotheses were formulated in pursuit of the aims of the study as outlined in Chapter 1.

H_0 : Motor performance in children is not predicted by dynamic visual acuity and VH or the presence of SNHL.

H_1 : Motor performance in children is predicted by dynamic visual acuity and VH or the presence of SNHL.

3.3 Research setting

The study was conducted in two phases. During the first phase, the inter-rater and intra-rater reliability of the SCPNT, DVA and the M-ABC-2 was conducted at a school for deaf children. The second phase was an empirical study to evaluate the motor performance, visual acuity and vestibular function of children with SNHL attending an inclusive South African mainstream school for children with normal-hearing and for children with hearing loss. It is a parallel-medium school, catering for children in classes where either English or Afrikaans is used as medium of teaching. This mainstream school is unique because of the inclusion of a few children with hearing loss into regular classes where they can learn alongside their peers with normal hearing. The emphasis is on spoken language, and children with hearing loss are not allowed to use sign language. All the classrooms are acoustically treated, providing a quiet learning environment. The teachers are academically qualified, with special training for an inclusion programme, and they are supported by classroom

assistants who are students in education. The benchmark is 25 children per class, and the total number of pupils in the pre-school and primary school is 470.

3.4 Participants

The participants of the reliability study were all children with SNHL attending a special school for deaf children. The main study participants were all children attending a school that caters for children with no hearing impairment as well as children with hearing impairment. All children were between the ages of four and thirteen years old. This age group was chosen because the M-ABC-2 and DVA tests used in the study have been proved to be valid and reliable for this age group. As the intention was to establish and compare the prevalence and impact of possible BVH in children there were two groups of participants: children with SNHL (SNHL group) and those with normal hearing.

The inclusion criteria for the SNHL group were:

- Children with a congenital or early acquired (before the age of two years) SNHL were included in the study. An audiologist of each school who was familiar with the medical history of the children and who had access to their records selected the children with SNHL and matched them with normal-hearing children according to age and gender.
- Children with correctable visual impairment were included in the study. Parents were asked screening questions to determine whether visual problems had been identified by a qualified optometrist.
- Both male and female participants were included in the study.

The exclusion criteria for the SNHL group were:

- Children with neurological problems, such as cerebral palsy, brain damage or other central nervous system impairments who had been diagnosed by a neurologist were excluded as neurological damage could have resulted in diminished motor function and could have confounded results (Diamond, 2000).
- Children who were reportedly taking medication and who had ocular side-effects were excluded.

- Children with cochlear implants were not tested within three months of the surgery because of the possible effect of the surgery on the vestibular system (Cushing et al., 2008; Filipo et al., 2006).
- Children with conductive hearing loss that was identified by a professional and reported by the parents were excluded because vestibular problems in this group tend to be transient (Casselbrandt & Mandel, 2005).
- Children with learning disabilities who were reported by the parents or teacher were excluded from the study because the SCPNT is not a reliable test for children with learning disabilities (Morrison & Sublett, 1983).
- Children with spontaneous nystagmus were excluded because it would have been difficult to establish whether nystagmus seen after vestibular stimulation is of vestibular origin or not. Before children were tested, the principal investigator looked for spontaneous nystagmus through Frenzel lenses.
- Children with poor visual acuity that was not correctable and that was reported by the parents were also excluded.

To establish whether the abovementioned criteria were identified in the participants, parents were asked to complete a questionnaire addressing all these issues. Refer to Appendix C for the screening questionnaire.

Male and female participants with reportedly normal hearing were included in the control group and they were matched with the SNHL group according to age and gender.

Exclusion criteria for the normal-hearing group were:

- Neurological problems such as cerebral palsy, brain damage or other central nervous system impairments that were diagnosed by a neurologist, as neurological damage could have resulted in diminished motor function and confounded results (Diamond, 2000).
- Children reportedly taking medication that has ocular side-effects.
- Children with learning disabilities that were reported by the parents or teacher were excluded from the study because the SCPNT is not a reliable test for children with learning disabilities (Morrison & Sublett, 1983).
- Children with spontaneous nystagmus were excluded because it would have been difficult to establish whether nystagmus seen after vestibular stimulation

is of vestibular origin or not. The principal investigator evaluated the eyes for spontaneous nystagmus through Frenzel lenses before tests were conducted.

- Children with poor visual acuity that was not correctable were excluded.

To establish whether the abovementioned criteria were identified in the participants, parents had to complete a questionnaire addressing all these issues. Refer to Appendix D.

3.5 Sample size

For the first phase of the study a convenience sample of twenty children between the ages of four and thirteen years old with congenital or early acquired SNHL who met the inclusion criteria were selected. Phase 1 of the study was conducted at the school for the deaf to test the inter-rater and intra-rater reliability of the M-ABC-2, the DVA test and the modified SCPNT. Selection was based on consent of the parents and the availability and willingness of the children to participate. As the intention was to test the reliability of the tests within the research setting, the original sample size was 20, with the intention that it would be increased until reliability criteria had been met.

The sample size for the main study was established by using an on-line sample size calculator for multiple regression analysis, accessed on 14 January 2010. The participants of the first phase of the study were not included in the main study.

The web-state outlines the procedure for calculation:

‘There are several formulae involved in the computation of an *a-priori* sample size for multiple regression. These formulae are detailed below.

F-distribution probability density function:

$$\frac{1}{B(d_1/2, d_2/2)} \left(\frac{d_1 x}{d_1 x + d_2} \right)^{d_1/2} \left(1 - \frac{d_1 x}{d_1 x + d_2} \right)^{d_2/2} x^{-1}$$

where d_1 and d_2 are the numerator and denominator degrees of freedom respectively, and B is the beta function.

Noncentrality parameter for the F-distribution (lambda):

$$f^2 n$$

where f^2 is the effect size and n is the sample size.

Noncentral F-distribution probability density function:

$$\sum_{k=0}^{\infty} \frac{e^{-\lambda/2} (\lambda/2)^k}{B\left(\frac{\nu_2}{2}, \frac{\nu_1}{2} + k\right) k!} \left(\frac{\nu_1}{\nu_2}\right)^{\frac{\nu_1}{2} + k} \left(\frac{\nu_2}{\nu_2 + \nu_1 f}\right)^{\frac{\nu_1 + \nu_2}{2} + k} f^{\nu_1/2 - 1 + k}$$

where ν_1 and ν_2 are the numerator and denominator degrees of freedom respectively, λ is the noncentrality parameter, f is the Fisher F-value, and B is the beta function.

Normal curve cumulative distribution function:

$$\frac{1}{2} \left(1 + \operatorname{erf} \frac{x - \mu}{\sigma \sqrt{2}} \right)$$

where μ is the mean, σ is the standard deviation, and erf is the error function.'

The values entered into the equation were an alpha (p value) of 0.05, three predictors (SNHL, DVA and VH), and a medium effect size of 0.2 as well as a power level of 0.8 (80%). A total of 52 participants needed to enrol. A total of 64 participants took part in the current study.

3.6 Instrumentation

In addition to a biographical questionnaire to establish history and to identify exclusion criteria and a classification of degree of hearing impairment, three tests were utilised in this study, namely the M-ABC-2 to measure motor function, the DVA test to test visual acuity and the modified SCPNT to detect the responsiveness of the horizontal SCC.

3.6.1 Biographical questionnaire

A biographical questionnaire concerning the age, gender, and previous and present health status of each participant was completed by the parent/s or guardian (see Appendices C and D). A pilot study was done on the parents or guardians of five children to make sure that the questions were clear and unambiguous. The pilot

study was conducted with a subsample of the proposed sample (Kanjee, 2006). The same procedures were followed for the pilot study and the first phase of the study.

3.6.2 Classification of degree of hearing impairment

The classification system for hearing loss in children provided by Northern and Downs (2001) was used to categorise the degree of hearing loss. (See 2.2) This system was used because the effect of hearing loss in children is different from that in adults. Congenital or early acquired hearing loss has a dramatic impact on learning spoken language (Northern & Downs, 2001).

3.6.3 Frenzel lenses

Otometrics FL-15 Frenzel lenses can be used to make nystagmus more observable and also to prevent fixation that can inhibit nystagmus. Frenzel lenses were utilised in this study.

3.6.4 The M-ABC-2

The M-ABC-2 has been found to be a reliable and valid test of motor performance in children, and its reliability within the current research setting was established (see 3.7).

For each participant, the appropriate age band was selected according to the age of the child. Age Band 1 (AB1) was designed for four- and six-year-olds, Age Band 2 (AB2) for seven- to ten-year-olds, and Age Band 3 (AB3), for 11- to 16-year-olds. The investigator demonstrated and described to each participant what was expected of him/her. The test items of the M-ABC-2 are described in detail in Appendix E.

The M-ABC-2 results are given as a raw score, a standard score which is norm-referenced for the child's age, a percentile for each component (manual dexterity, aiming and catching and balance) and a total score.

The standard scores of the three different components (manual dexterity, ball skills and balance) and the standard total test score of the M-ABC-2 were used in the statistical analysis. The standard score for the three different components and the total test score ranged between a minimum of one and a maximum of 19. In this test, a standard score of eight or more means that no movement difficulty is present. A standard score of six or seven suggests that the child is at risk of a movement

difficulty and a standard score of five or less indicates a significant movement difficulty.

3.6.5 The dynamic visual acuity (DVA) test

The DVA test provides a functional measure of the VOR. The inter-rater and intra-rater reliability were established within the context of this study (see 3.7). Each participant was introduced to the distance chart. A decision was made with the cooperation of each participant upon names that would be used to identify the symbols. The participant was then seated in a chair three metres from the chart placed at eye level, and was asked to identify the symbols, using best corrected vision. The participant began to identify symbols on the middle line (20/200). This was continued for successive lines until the participant missed three of the five optotypes on a line. The log MAR values of this line and those of the lowest line for which all the optotypes were correct were recorded (Rine & Braswell, 2003). This was done under two conditions: (1) head stationary, and (2) head tilted forward and the neck in 30° of flexion and manually rotated 30° by the researcher (sinusoidally, 15° from centre to the left and to the right), to the beat of a metronome at 2 Hz (hDVA). The amplitude of head movement was controlled by the use of a hat with a large brim extension that tapped a bar during manually imposed movement and stopped rotation at 15° in either direction. Two trials of SVA and four trials of hDVA were done. The average of the two SVA trails and the average of the third and fourth hDVA trails were used. The rationale for discarding the first and second hDVA results was to allow the participant to become accustomed to the task. In order to prevent the participant from guessing, different charts were used for each trial to limit any possible learning effects. A dynamic visual acuity score is then calculated as the difference between static visual acuity (SVA) and dynamic visual acuity (hDVA) in lines by using the formula:

$$\text{DVA score} = \text{abs} [(\text{SVA logMAR} \times 10)] - [(\text{DVA logMAR} \times 10)]$$

To establish the prevalence of decreased dynamic visual acuity the DVA score was calculated by determining the difference between the average of the two SVA trails and the average of the last two hDVA trails. A DVA score of more than two indicates more than two lines difference between SVA and hDVA (Rine & Braswell, 2003).

This is an indication of gaze instability most likely due to a vestibular defect (Rine & Braswell, 2003). The DVA score was used in the statistical analysis.

3.6.6 The SCPNT

As noted in Chapter 2, there is controversy about the reliability of the SCPNT. In the current study every effort was made to control for different aspects that could influence the accuracy of the test on different occasions. In this study, an office chair that could rotate was used instead of a board. The back support of the chair provided extra trunk support. A Velcro strap was placed around the child's body to keep the trunk in position. The neck was put in 30° flexion to ensure optimal stimulation of the horizontal SCC. The head was kept in this position by a Somi neck brace that was modified to fit a child's body. The shoulder pieces were narrowed, the chin support was shortened, and more holes were made into the part overlying the chest. The occipital part of the brace was removed and a Velcro strap was attached to the chin support to ensure that the participant's neck stayed in 30° of flexion. Frenzel lenses were used to prevent fixation and to enhance observation of nystagmus. Moreover, the test was performed in a dark room to further prevent visual fixation. The chair was rotated manually to one side at a constant speed of 1 Hz (one rotation per second) ten times. To improve accuracy the rotation of the chair was done to the beat of a metronome. The participant was encouraged to count the rotations together with the examiner to maintain mental alertness. The chair was then stopped suddenly, and the nystagmus was video recorded through the Frenzel lenses. This enabled the researcher to evaluate the nystagmus more than once to improve accuracy. Both inter-rater and intra-rater reliability were established in the South African context (see 3.7).

Vestibular hyporesponsiveness was indicated by a duration of nystagmus (as induced by the modified SCPNT) of less than or equal to eight seconds (Ayres, 1989; Rine et al., 2000). The number of beats of nystagmus in ten seconds was used in addition to the duration of nystagmus. The rationale for adding the number of beats in ten seconds was to get an indication of the speed of the nystagmus and also to allow for extra time to observe nystagmus because the number of beats of nystagmus may be influenced by the position of the eye in the orbit (Tusa, 2007).

3.7 Procedure

Ethical approval of the study was obtained from the Faculty of Health Science Human Research Ethics Committee of the University of Cape Town (Appendix F). The study was conducted in two phases. The first phase was done at a school for the deaf. During the first phase, the inter-rater and intra-rater reliability of M-ABC-2, the DVA test and the modified SCPNT test were established within the research setting. The second phase was done at the mainstream school. In the second phase, the motor skills, visual acuity and vestibular function of participants with SNHL and those of normal-hearing children were tested, and the results were compared. All the tests were performed in the same order. Periods of rest were allowed to ensure that participants were able to concentrate on the activities. Participants with hearing aids were allowed to wear their hearing aids to facilitate communication.

3.7.1 Phase 1

Permission to do the study at the school for the deaf was obtained from the principal of the school (Appendix G). A convenience sample of twenty children between the ages of four and thirteen years old with an early acquired SNHL or with congenital SNHL was selected. Convenience sampling is used where universal processes are supposedly examined (Durrheim, 2006). However, a convenience sample is not representative of the population of children with SNHL (Durrheim, 2006). Informed consent to take part in the study was obtained from the parents/legal guardians of the children (Appendix H). A pilot study was done on five children to identify potential problems with the proposed research. The pilot study was conducted with a subsample of the proposed sample, as described by Kanjee (2006). As the pilot study did not highlight any procedural issues, the same procedures were followed for the pilot study and the first phase of the study. The parent/legal guardian of each child completed a questionnaire regarding the child's current and previous medical history (Appendix D). The procedure was explained to each participant. The participant was informed that he/she might experience some dizziness for a few seconds after the modified SCPNT. The participant was also informed that he/she could withdraw from the study at any time without any negative effects. Assent was obtained from each participant to take part in the procedure (Appendix I).

To test the inter-rater reliability of the M-ABC-2 the results obtained by the principal investigator and another experienced physiotherapist, who observed the participant's

performance simultaneously, were compared. To establish the intra-rater reliability the M-ABC-2 was performed by the principal investigator twice, one week apart, on the same sample of participants, and the results obtained on the two different occasions were compared.

To test the inter-rater reliability of the DVA test, the test was performed by two investigators, and the average of the two SVA trails and the average of the last two trials of hDVA were then compared. To test the intra-rater reliability of the DVA test the principal investigator tested the same sample of participants on two different occasions. The results (average of the two SVA trails and the average of the last two trials of hDVA) obtained on the two occasions were then compared.

To evaluate inter-rater reliability of the SCPNT, the principal investigator as well as an experienced medical practitioner specialising in balance disorders and dizziness evaluated the recorded modified SCPNT independently. Both the number of beats of nystagmus and the duration of nystagmus after leftward rotation as well as rightward rotation were evaluated separately. These results were then compared. To test the intra-rater reliability of the modified SCPNT, participants were evaluated by the principal investigator on two different occasions, one week apart. The results obtained on the two different occasions were then compared.

Participants received a small reward, such as a sticker or a pen, to thank them for their willingness to take part in the study.

3.7.2 Phase 2

Permission to do the study at the inclusive mainstream school was obtained from the principal of the school (Appendix J). Permission was also obtained to have access to the school records of the children with SNHL who were taking part in the study.

The SNHL group consisted of all children with SNHL who fitted the inclusion criteria and whose parents gave informed consent for them to take part in the study. The normal-hearing group consisted of age- and gender-matched normal-hearing children from the same school. Informed consent was obtained from the parents/legal guardians of both groups of children (Appendices K and L). Parents/legal guardians completed a questionnaire regarding the children's current and previous medical history (Appendices D and E). The parents were contacted telephonically to arrange appointments to evaluate the children at school. Assent

was obtained from each participant to take part in the procedure (Appendix I). School-going participants were evaluated after school hours at the school. Nursery school participants were evaluated during school hours at the school to ensure that they were not tired and could concentrate optimally. The total duration of all the tests for each participant was approximately 60 minutes.

The following procedures were performed on both groups of participants:

- the M-ABC-2
- the DVA test
- the modified SCPNT.

The M-ABC-2, DVA and the modified SCPNT test were conducted in the same sequence as described in phase 1 of the study. It was decided to place the modified SCPNT last in the test order as it was thought possible that this would be the most taxing of the tests. It was anticipated that children could find this test the most distressing, and placing it last in the test sequence would prevent refusal of the next tests.

3.8 Data management

SPSS Version 17, 2007® was used to do the statistical analysis of this study. Epi-Info Stat Calc Version 6 was used to calculate odds ratios and 95% confidence intervals.

During data capture, the researcher re-entered a sample of the data and a comparison of the two separate records was undertaken with the following formula:

$$(\text{Agreement})/(\text{Agreement} + \text{Disagreement}) \times 100$$

Intra-rater reliability of $\geq 90\%$ was accepted (Johnson & Danhauer, 2002). Five percent of the overall sample was subjected to this measure (Johnson & Danhauer, 2002). The intra-rater reliability for the first phase of the study was 100% and for the second phase of the study, 96%.

3.9 Data analysis

3.9.1 Reliability

Inter-rater and intra-rater reliability of the M-ABC-2, the DVA test and the modified SCPNT was assessed by determining the intra-class correlations (ICC). As both the

choice of child and of examiner was random, a two-way random effects model was used (McGraw & Wong, 1996). In addition, the absolute agreement, rather than consistency was examined and this was at the level of the individual rather than at the group level (McGraw & Wong, 1996).

3.9.2 Association between impairments in DVA, vestibular function and motor performance

Association between impairments in DVA and VA was determined by using chi-square analysis. The one sided chi-square test or, if there were any cells with less than five, the Fisher's exact test, were used to test whether there was an association between SNHL and VH and poor dynamic visual acuity.

As the Shapiro-Wilk test indicated that the majority of M-ABC-2 data sets were not normally distributed, the Mann-Whitney U-test was used to analyse data in order to determine whether there was a significant difference in the ranking of the scores on the M-ABC between children with VH and children without VH, and between children with SNHL and those with normal hearing (Lachenicht, 2002a).

3.9.3 Predictors of M-ABC-2

To establish the predictors of the M-ABC-2 total standard score, dummy variables were created for the presence of reduced DVA, reduced duration of nystagmus, the presence of SNHL and gender. These variables, with age in years included, were entered into a forward stepwise regression model. This was followed by residual analysis.

As the scores of the children with normal hearing and those with a mild to moderate SNHL appeared to be similar, the Kruskal-Wallis test, the non-parametric equivalent of the one-way ANOVA, was used to compare the rank ordering of the scores of these three groups (Lachenicht, 2002a).

3.10 Ethical considerations

Children are considered a vulnerable population by the Medical Research Council (MRC). Special precautions are therefore necessary to minimise risks and to protect children from potential harm. It is also important that the potential benefits of the research must outweigh the foreseeable risks (Medical Research Council, 2004).

To determine whether research is ethical, four widely accepted principles are applied in various ways (Wassenaar, 2006), namely:

- **Autonomy and respect for the dignity of persons:** This includes informed consent and confidentiality. Informed consent was obtained from the parent/s or legal guardians of the children. All information obtained in this study was and will be regarded confidential. Each participant received a number and only the principal investigator has access to the identities of the children. Data that may be reported in scientific journals will not include any information that identifies specific children. Results will be revealed to the management of the school, without revealing the identities of individual children. Participation was voluntary. If a participant did not want to complete a test he/she was not forced to participate. Withdrawal from the study had no negative effects on attitudes towards the child. Assent was obtained from each participant before starting the test procedures. Assent was also obtained between test procedures and as a continual process each time a test was repeated (Wassenaar, 2006).
- **Nonmaleficence:** This requires that the researcher will ensure that no harm will befall research participants (Wassenaar, 2006). The current study posed no risks for the participants. The only potential discomfort was the possible vertigo that participants could experience after the rotations on the chair. This vertigo only lasted for a few seconds. Children in the study group could have been familiar with the sensation induced by the rotations as it would have been similar to what they would have experienced on a merry-go-round on the playground, so it was unlikely that they would have reacted negatively. If the participant showed alarm or experienced anxiety he/she was comforted by the examiner. Most participants enjoyed performing the tests used in this study. To ensure the children's safety, an office chair with armrests was used. The chair was fitted with a seat belt and the chair was also secured on the floor. The participants were instructed to sit with crossed legs and to hold on to the armrests.
- **Beneficence:** The researcher must always attempt to maximise the benefits that the research will afford to the participants of the research (Wassenaar, 2006). The potential benefits of the research outweigh the risks. If a positive

relationship between motor performance, VH and dynamic visual acuity is found, an intervention study might be indicated, using vestibular rehabilitation therapy (VRT). If a significant motor delay or VH was identified during the evaluation of the participants, the parents/legal guardians were informed about it and the participant was referred for appropriate intervention.

- Justice: This requires that the researcher treat the research participants with equity and fairness during all stages of the research and that participants are able to benefit from the outcome of the research if possible (Wassenaar, 2006). This principle was adhered to and all eligible participants with SNHL were given an equal opportunity to participate.

3.11 Physiotherapy in South Africa

The Health Professions Council of South Africa (HPCSA) defines physiotherapy as a supplementary service to medicine. The physiotherapist is a first-line practitioner who renders physiotherapy services to the public. The scope of the profession of physiotherapy includes the following: rehabilitation of patients with neurological deficits and post-neurosurgery, rehabilitation of the patient to his/her maximum potential both in work and sport, including adaptation to permanent disabilities, paediatrics, maintenance and restoration of physical fitness, other surgical and medical fields that may require physiotherapy services and exercise therapy. It falls within the scope of practice of a physiotherapist to evaluate children and to do rehabilitation therapy to assist such children to maximise their potential.

The SCPNT and the M-ABC-2 used in this study fall within the scope of practice of a physiotherapist, and the DVA-test is being taught at a course in the USA for physiotherapists, occupational therapists and medical doctors to evaluate dynamic visual acuity and vestibular function. The DVA test was also included in the first South African vestibular assessment rehabilitation therapy (VART) course that was held in January 2009.

The principal investigator has been in clinical practice for 20 years and successfully completed a competency-based course in vestibular rehabilitation offered by the Emory University School of Medicine and the American Physical Therapy Association in March 2007.

4 RESULTS

In this chapter, the results of the empirical investigation will be reported. The results of the reliability study will first be described, followed by results of the second phase (main study) of the study.

4.1 Reliability study

4.1.1 Subject characteristics

There were 20 participants in the reliability study, of whom 11 were female. The mean age was 8.2 years (standard deviation, SD 2.2), ranging from 4.8 to 12.5 years of age (Table 3). All the children were diagnosed with early or congenital bilateral SNHL.

Table 3: Ages in years of participants in the reliability study (N=20)

Age	4.8	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	Total
Frequency	1	3	2	3	5	1	3	1	1	20

4.1.2 Inter- and intra-rater reliability of the M-ABC-2

The majority of inter-rater and intra-rater ICC of the different components of the M-ABC-2 was above 0.8 (Table 4 & 5).

Table 4: Intra-rater ICC values for M-ABC-2 component standard scores and percentiles and overall score (N=20).

Measurement	Rater 1 First occasion mean, SD, range	Rater 1 Second occasion mean, SD, range	Correlation	ICC	95% Confidence interval lower bound	95% Confidence interval upper bound
M-ABC total standard score	7.45 (SD3.1 range 1–12)	7.95 (SD 3.1 range 2–13)	Intra-rater	0.870	0.701	0.946
M-ABC total percentile	28.33 (SD26.49 range 1–84)	32.63 (SD26.49 range 0–75)	Intra-rater	0.807	0.575	0.919
M-ABC manual dexterity standard score	6.55 (SD2.6 range 2–13)	7.05 (SD2.8 range 2–13)	Intra-rater	0.764	0.496	0.900
M-ABC manual dexterity percentile	18.7 (SD20.67 range 1–84)	23.23 (SD24.04 range 1–84)	Intra-rater	0.732	0.438	0.885
M-ABC aiming & catching standard score	10.2 (SD2.67 range 5–15)	10.45 (SD3.14 range 5–15)	Intra-rater	0.852	0.664	0.939
M-ABC aiming & catching percentile	52.40 (SD28.87 range 5–95)	55.35 (SD31.5 range 5–95)	Intra-rater	0.859	0.678	0.942
M-ABC balance standard score	7.80 (SD2.99 range 3–14)	8.60 (SD2.95 range 3–14)	Intra-rater	0.864	0.688	0.944
M-ABC balance percentile	30.70 (SD 24.39 range 1–91)	30.65 (SD24.44 range 0–91)	Intra-rater	1.000	0.999	1.000

Table 5: Inter-rater ICC values, means, SD and range for M-ABC-2 component standard scores and percentiles

Measurement	Rater 1 mean, SD, range	Rater 2 mean, SD, range	Correlation	ICC	95% Confidence interval lower bound	95% Confidence interval upper bound
M-ABC total standard score	7.45 (SD 3.1 range 1–12)	7.5 (SD 2.97 range 2–12)	Inter-rater	0.864	0.693	0.944
M-ABC total percentile	28.33 (SD 26.49 range 1–84)	28.35 (SD 23.66 range 1–75)	Inter-rater	0.891	0.730	0.956
M-ABC manual dexterity standard score	6.55 (SD 2.6 range 2–13)	6.65 (SD 2.6 range 2–13)	Inter-rater	0.985	0.963	0.994
M-ABC manual dexterity percentile	18.7 (SD 20.67 range 1–84)	19.35 (SD 20.76 range 1–84)	Inter-rater	0.983	0.958	0.993
M-ABC aiming & catching standard score	10.2 (SD 2.67 range 5–15)	10.25 (SD 2.73 range 5–15)	Inter-rater	0.997	0.991	0.999
M-ABC aiming & catching Percentile	52.40 (SD 28.87 range 5–95)	52.75 (SD 29.32 range 5–95)	Inter-rater	0.999	0.996	0.999
M-ABC balance standard score	7.80 (SD 2.99 range 3–14)	7.70 (SD 3.16 range 1–14)	Inter-rater	0.973	0.932	0.989
M-ABC balance percentile	30.70 (SD 24.39 range 1–91)	30.66 (SD 24.44 range 0–91)	Inter-rater	1.000	0.999	1.000

4.1.3 Inter-rater and intra-rater reliability of the DVA test

Because the DVA score is calculated as the difference between static visual acuity (SVA) and horizontal dynamic visual acuity (hDVA) in lines (Rine & Braswell, 2003), the reliability of each of these was calculated. The mean line at which three mistakes were made for the hDVA, the SVA and the DVA scores of the first rater on both occasions and that of the second rater were used to determine the ICC. The ICC exceeded 0.8 for all inter-rater scores but fell below this for intra-rater scores (Table 6).

Table 6: Mean DVA and SVA lines at which three mistakes were made and the DVA score in lines of the raters and the ICC (N=20)

Measurement	Rater 1 first occasion	Rater 1 second occasion	Correlation	ICC	95% Confidence interval lower bound	95% Confidence interval upper bound
SVA line at which three mistakes were made	.04 (SD .18, range -.1 to .5)	-.03 (SD .13, range - .1 to .4)	Intra-rater	0.674	0.256	0.873
hDVA line at which three mistakes were made	.06 (SD .25, range -.5 to .55)	.07 (SD .18, range -.10-.45)	Intra-rater	0.887	0.733	0.955
DVA score	.83 (SD .88, .00 to 3.00)	.78 (SD .99, range .00 to 3.00)	Intra-rater	0.579	0.186	0.81
Measurement	Rater 1	Rater 2	Correlation	ICC	95% Confidence interval lower bound	95% Confidence interval upper bound
SVA line at which three mistakes were made	.04 (SD .18, range -.1 to .5)	.05 (SD .17, range -.1 to .5)	Inter-rater	.982	0.952	0.993
hDVA line at which three mistakes were made	.06 (SD .25, range -.5 to .55)	.05 (SD.22, range -.5 to .55)	Inter-rater	0.838	0.634	0.933
DVA score	.83 (SD .88, .00 to 3.00)	.73 (SD .85, range .00 to 3.00)	Inter-rater	0.883	0.733	0.952

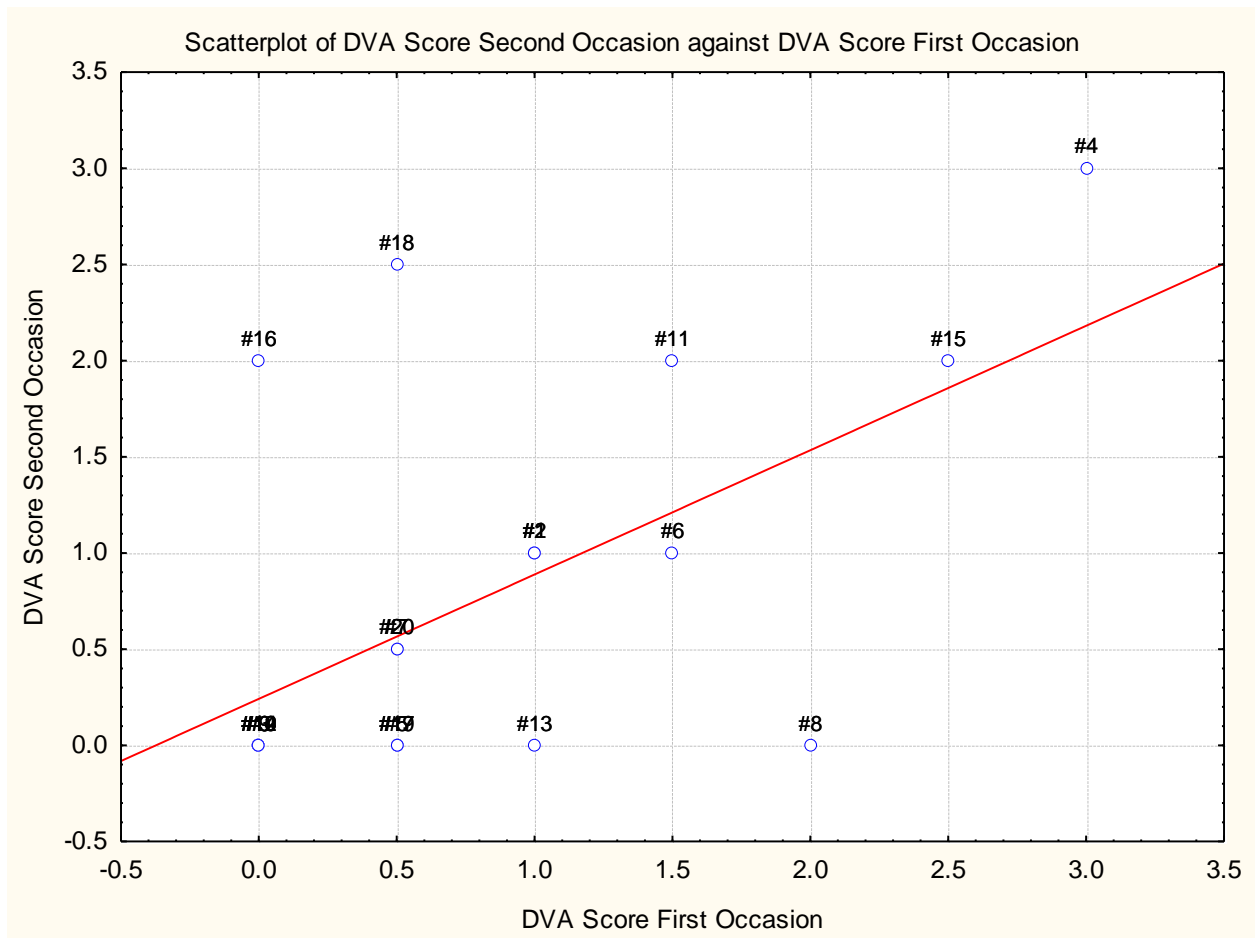


Figure 1: Scatterplot of the intra-rater DVA test-retest scores in lines (ICC=0.58, N=20, note that some points have multiple cases)

There were four outliers who obtained a DVA score of 0.5 or below on one occasion and above 1 on the other (Figure 1).

4.1.4 Inter and intra-rater reliability of the SCPNT

The inter-rater and intra-rater ICC values of the modified SCPNT were greater than 0.9 (Table 7).

Table 7: ICC for duration and number of beats of nystagmus after SCPNT to the left and right (N=20-18).

Measurem ent	Rater 1 First occasion mean, SD, range	Rater 1 Second occasion mean, SD , range	Correlation	ICC	95% Confidenc e interval lower bound	95% Confidenc e interval upper bound
SCPNT duration L	22.6 (SD 13.2 range 0–55)	21.74 (SD 10.52 range 40–52)	Intra-rater	0.932	0.833	0.973
SCPNT duration R	20.00 (SD 10.43 range 2–47)	19.11 (SD 8.68 range 5–40)	Intra-rater	0.965	0.913	0.987
SCPNT beats L	21.21 (SD 19.23 range 0–84)	20.16 (SD 12.72 range 2–56)	Intra-rater	0.890	0.738	0.956
SCPNT beats R	17.47 (SD 13.82 range 1–47)	18.68 (SD 11.93 range 4–47)	Intra-rater	0.923	0.812	0.970
Measurem ent	Rater 1 mean, SD, range	Rater 2 mean, SD, range	Correlation	ICC	95% Confidenc e Interval Lower Bound	95% Confidenc e Interval Upper Bound
SCPNT duration L	22.60 (SD 13.2 range 0–55)	22.67 (SD13.43 range 0–57)	Inter-rater	0.992	0.980	0.997
SCPNT duration R	20.00 (SD1 0.43 range 2–47)	19.89 (SD11.12 range 0–46)	Inter-rater	0.994	0.983	0.998
SCPNT beats L	21.21 (SD 19.23 range 0–84)	22.17 (SD 20.08 range 0–88)	Inter-rater	0.995	0.986	0.998
SCPNT beats R	17.47 (SD 13.82 range 1–47)	17.94 (SD 14.29 range 0–48)	Inter-rater	0.994	0.984	0.998

Duration L = Duration of nystagmus after the SCPNT was performed to the left.

Duration R = Duration of nystagmus after the SCPNT was performed to the right.

Beats L = Number of beats of nystagmus after the SCPNT was performed to the left.

Beats R = Number of beats of nystagmus after the SCPNT was performed to the right.

Two participants left the school before all the tests had been completed.

4.2 Main study

4.2.1 Subject characteristics

The sample of children with SNHL comprised 32 participants of which 15 were female. The mean age of the children was 9.35 years (SD 2.42, range 4.5 to 13.17)

(Table 8). There were 32 normal-hearing children of which 17 were males. The mean age of the participants was 9.38 years (SD 2.48, range 4.58 to 13.33).

Table 8: Ages of participants of main study in years

With SNHL		Normal hearing	
Age	Frequency	Age	Frequency
4.50	1	4.58	1
5.25	1	5.25	1
5.83	1	5.66	1
5.92	1	5.83	1
6.33	1	6.42	1
6.42	1	6.50	1
7.08	1	7.33	1
7.17	1	7.58	2
7.75	2	8.08	1
8.72	1	8.66	1
8.92	2	8.83	1
9.00	1	8.91	1
9.25	1	9.17	2
9.42	2	9.33	1
9.50	1	9.42	1
10.08	1	9.50	1
10.25	1	10.08	1
10.33	1	10.25	2
10.92	1	10.33	1
11.17	2	11.08	2
11.42	1	11.50	2
11.67	1	11.66	1
11.74	1	12.25	1
11.83	1	12.75	1
12.25	1	13.00	1
13.08	2	13.33	2
13.17	1		
Total	32	Total	32

Of the initial sample of 35 potential participants with SNHL, 34 met the inclusion criteria and two children's parents did not give consent for participation in the study. The majority of children (26) were profoundly deaf and the rest had moderate to

slight hearing loss (Table 9). Although one of the participants fell within the limits of the normal category, the audiogram showed that there was a high frequency (above 3000 Hz) hearing loss that would result in difficulties with speech perception, and this child was included.

Table 9: Degree and frequencies of SNHL

Degree of SNHL	Frequency	Percent
Profound 71+ dB	26	81.3
Severe 51–70dB	1	3.1
Moderate 31–70dB	3	9.4
Slight 16-25dB	1	3.1
Within normal limits 0–15dB	1	3.1
Total	32	100

4.2.2 Dynamic visual acuity in participants with SNHL

Five participants had a difference of more than two lines between the DVA and SVA (Table 10). This translates into a prevalence of 15.6%. This means that 15.6% of participants had poor dynamic visual acuity.

Table 10: Values of DVA score in participants with SNHL (N=32)

DVA Score	0	0.05	0.5	0.95	1	1.5	2	3	4	Total
Frequency	10	1	2	1	6	3	4	3	2	32
Percent	31.3	3.1	6.3	3.1	18.8	9.4	12.5	9.4	6.3	100

All the participants with an abnormal DVA score were diagnosed with profound SNHL (Table 11).

Table 11: DVA score and degree of SNHL (N=32))

Degree of SNHL	DVA Score		Total
	≤2 (Nor)	>2 (Abn)	
Profound 71+dB	21	5	26
Severe 51–70dB	1	0	1
Moderate 31–50dB	3	0	3
Slight 16–25dB	1	0	1
Within normal limits 0–15dB	1	0	1
Total	27	5	32

Nor = Normal

Abn = Abnormal

4.2.3 Reduced responsiveness to the SCPNT in participants with SNHL

- Duration of nystagmus response post modified SCPNT

VH is indicated by a duration of nystagmus (as induced by the modified SCPNT) of less than or equal to eight seconds (Ayres, 1989; Rine et al., 2000). In the current study, the term *vestibular hyporesponsiveness* was chosen rather than VH because the SCPNT is not gold standard for determining VH. There were five participants with a duration of nystagmus of less than eight seconds who met the criterion for left vestibular hyporesponsiveness (Figure 2). This is a prevalence of 15.6%.

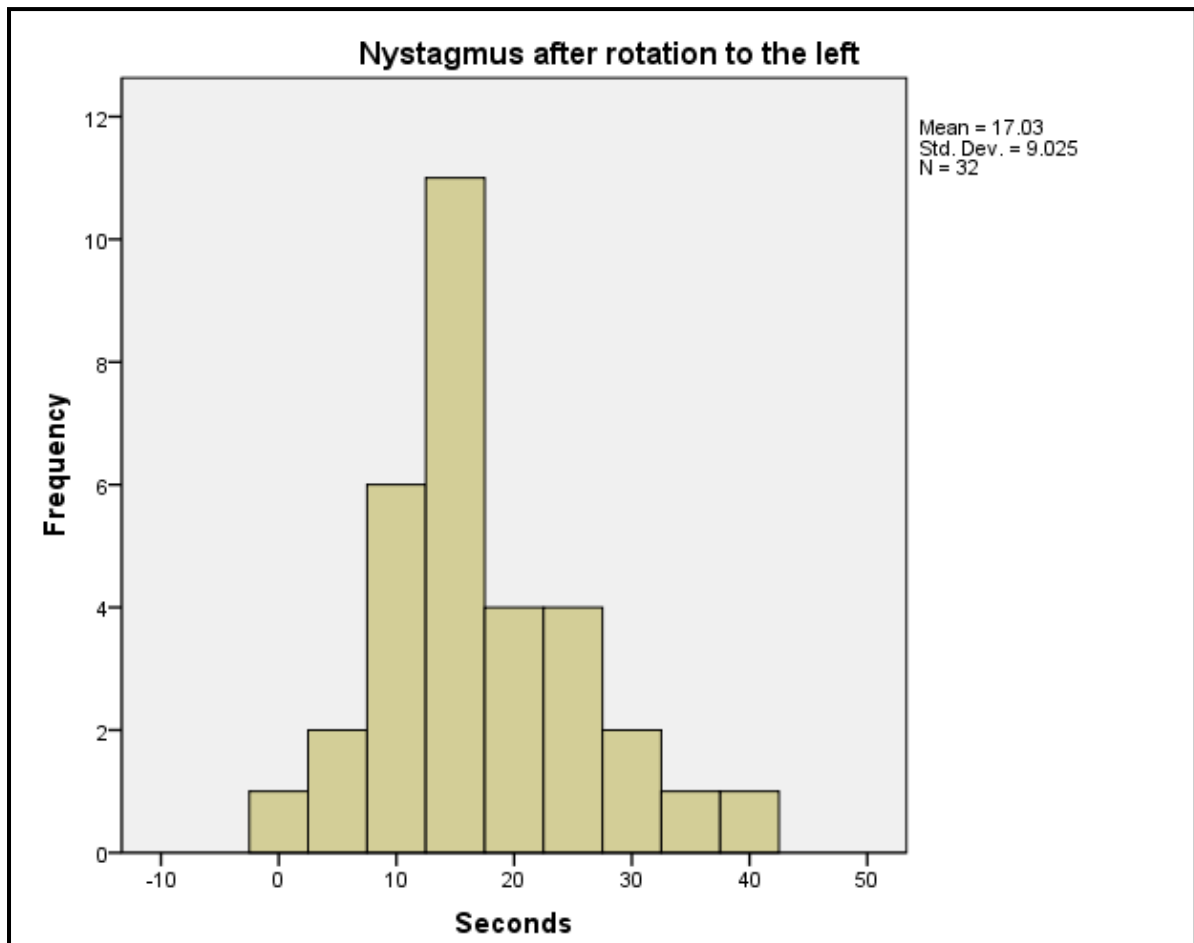


Figure 2: Duration of nystagmus in seconds after ten rotations to the left in the group with SNHL (N=32)

Four participants (13.3%) had a duration of nystagmus of less than eight seconds after rotations to the right (Figure 3). Two participants declined the test to the right.

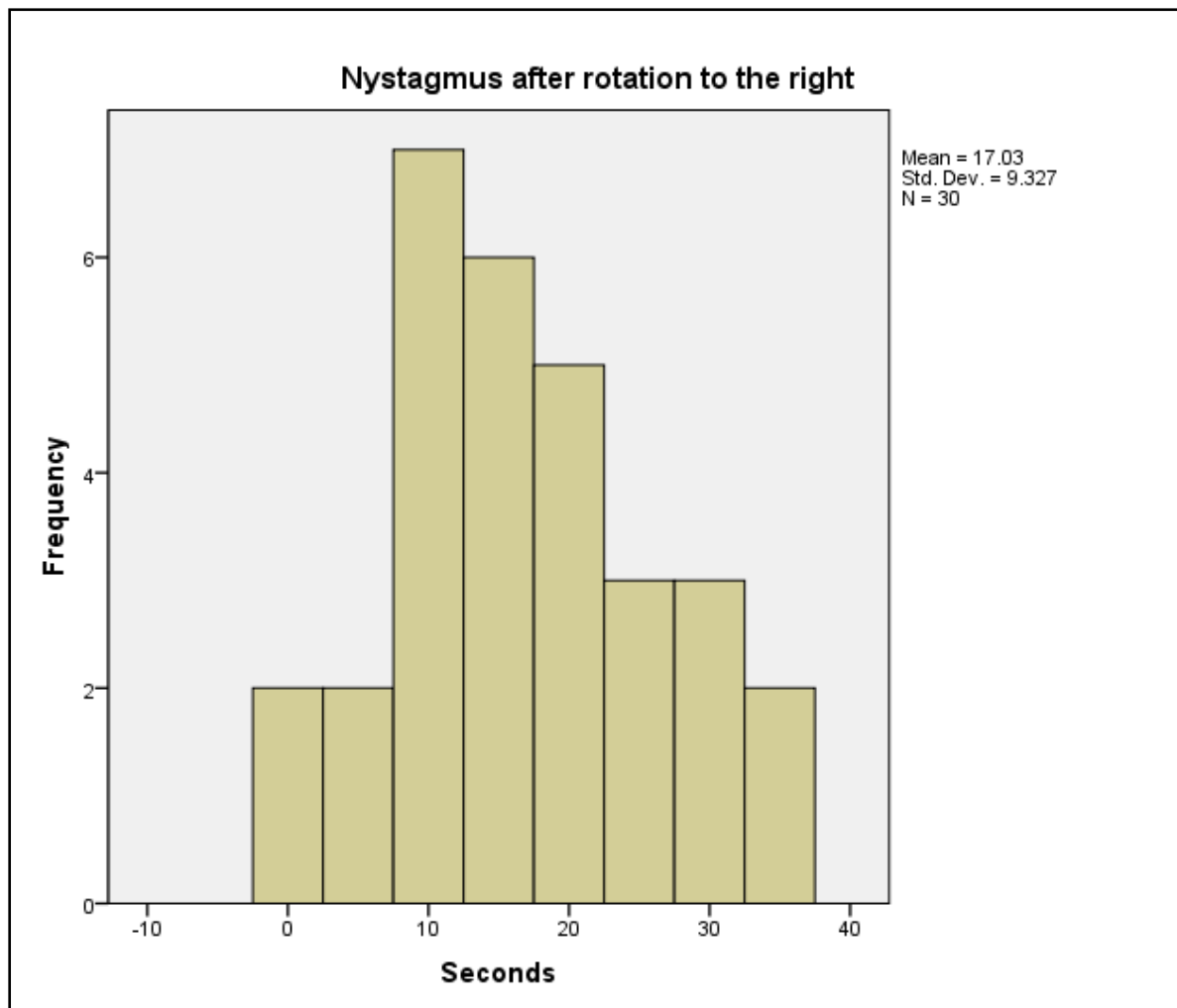


Figure 3: Duration of nystagmus in seconds after rotations to the right in the group with SNHL (N=30; two children refused to participate)

Three (10%) of the participants with a duration of nystagmus of less than eight seconds after rotations to the right were the same participants who had a duration of nystagmus of less than eight seconds after rotations to the left, suggesting bilateral reduced vestibular responsiveness. This leaves 5.6% of participants with SNHL with a left vestibular hyporesponsiveness and 3.3% of participants with SNHL with a right vestibular hyporesponsiveness. Two of the participants who had a duration of less than eight seconds to the left declined the test to the right.

- Number of beats of nystagmus in ten seconds post SCPNT

Eleven participants had less than ten beats of nystagmus in ten seconds after rotation to the left (Table 12). This translates into a prevalence of 34.4% of the sample who had a reduced response, which could suggest a possible left unilateral hyporesponsiveness. Two participants became upset and refused to continue the

test, meaning that rotation to the right could not be performed on them. These two individuals were among the group of participants with less than ten beats of nystagmus after rotation to the left. Ten of the 30 participants with SNHL who assented to rotation to the right, had less than ten beats of nystagmus in ten seconds. This resulted in a prevalence of 33.3%. This could suggest a possible right vestibular hyporesponsiveness.

Table 12: Number of beats of nystagmus in ten seconds after rotations to the left (N=32) and to the right (N=30)

	Rotation to the Left		Rotation to the Right	
Beats	Frequency	Percent	Frequency	Percent
0	1	3.1	2	6.3
2	1	3.1	2	6.3
3	2	6.3	1	3.1
5	1	3.1		
6	3	9.4	1	3.1
8	2	6.3	1	3.1
9	1	3.1	3	9.4
10	2	6.3	5	15.6
11	2	6.3		
12	5	15.6	2	6.3
13	3	9.4	3	9.4
14			2	6.3
15			1	3.1
16	2	6.3	2	6.3
17	2	6.3		
18	1	3.1		
19	1	3.1		
20			1	3.1
21	1	3.1		
22	1	3.1	2	6.3
25	1	3.1	1	3.1
			1	3.1
Subtotal			30	93.8
Missing			2	6.3
Total	32	100	32	100

When leftward rotation and rightward rotation were compared, eight participants (N=30) who assented to rotation in both directions, had less than ten beats of nystagmus after rotations to the left and right. This resulted in a prevalence of 26.6%

of participants with SNHL who had a reduced number of beats of nystagmus upon rotation to both the right and left, suggesting a possible bilateral hyporesponsiveness. This leaves 7.8% of the original 34.4% with a possible left reduced vestibular responsiveness and 6.7% of the original 33.3% with a possible right reduced vestibular responsiveness.

One participant that had less than ten beats of nystagmus in ten seconds after rotations to the left had ten beats of nystagmus in ten seconds after rotations to the right, suggesting either that beats of nystagmus could have been missed or that s/he has borderline normal or slightly asymmetrical function.

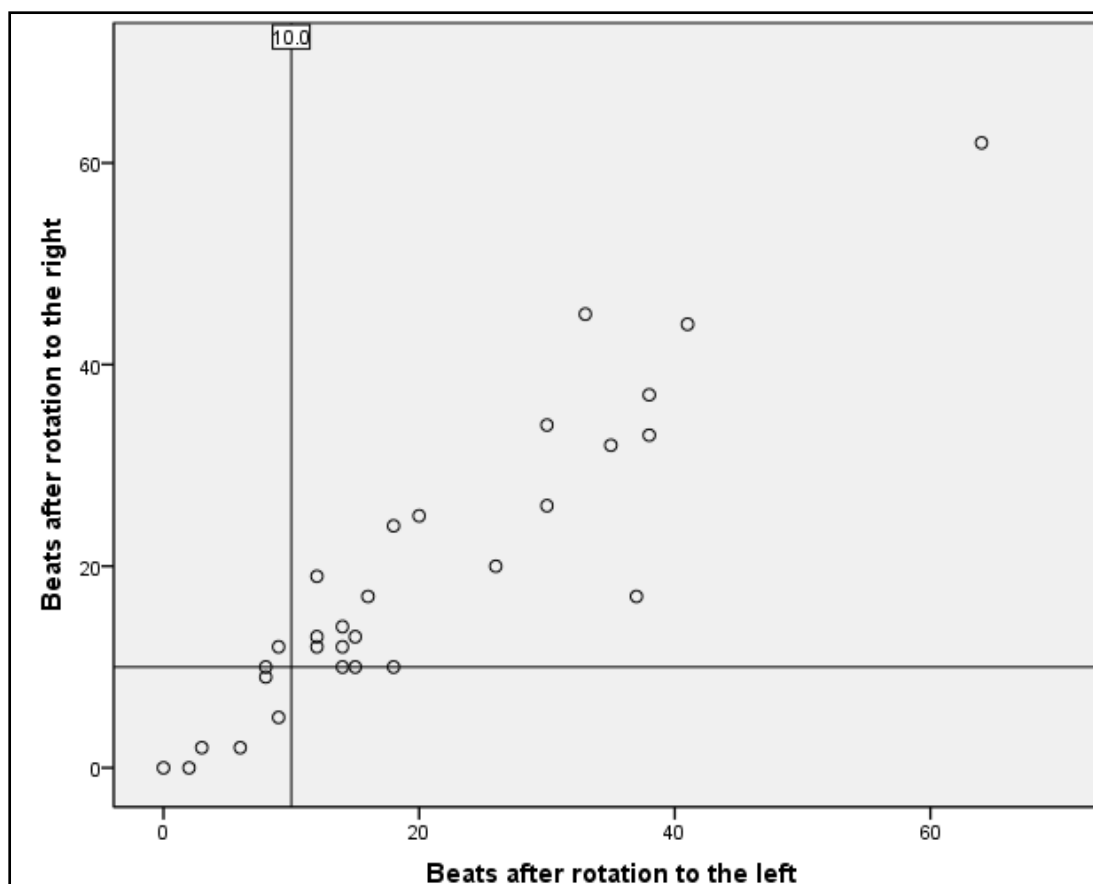


Figure 4: The majority of participants with less than 10 beats of nystagmus after rotations to the left had less than 10 beats of nystagmus after rotations to the right

The majority of children who had less than ten beats of nystagmus after rotations to the left also had less than ten beats of nystagmus after rotations to the right (Figure 4).

- Relationship between duration of nystagmus and number of beats of nystagmus in ten seconds

There were five participants with less than ten beats of nystagmus after rotations to the left and a duration of nystagmus of less than eight seconds after rotations to the left (Table 13). The one-sided Fisher's exact test indicated that less than ten beats of nystagmus and a duration of nystagmus of less than eight seconds were found to be associated (one-sided Fisher's exact $p=0.002$). The odd ratios (OR) could not be calculated due to a lack of children who had a duration of less than eight seconds and more than ten beats per ten seconds after rotations to the left (OR=infinity). In other words, every child with a decreased duration of nystagmus also had a decreased number of beats of nystagmus in ten seconds. The prevalence of both reduced duration of nystagmus and less than ten beats of nystagmus in ten seconds was 15.4%.

Table 13: Duration of nystagmus and amount of beats in ten seconds after SCPNT to the left (N=32)

	Beats/10 sec after left rotation		
Duration of nystagmus	<10	>10	Total
≤8sec	5	0	5
>8sec	6	21	27
Total	11	21	32

Fisher's exact $p=0.002$

There were four participants with less than ten beats of nystagmus after rotations to the right and a duration of nystagmus of less than eight seconds after rotations to the right (Table 14). This is a prevalence of 13.3%. The one-sided Fisher's exact test indicated that less than ten beats of nystagmus in ten seconds and a duration of nystagmus of less than eight seconds were found to be associated (one-sided Fisher's exact $p=0.027$).

Table 14: Duration of nystagmus and number of beats in ten seconds after the modified SCPNT to the right (N=30)

	Beats/10 sec after right rotation		
Duration of nystagmus	<10	>10	Total
≤8sec	4	0	4
>8sec	6	20	26
Total	10	20	30

Fisher's exact p=0.027

The four participants with less than ten beats of nystagmus and a duration of nystagmus of eight or less seconds after the rightward SCPNT were the same participants with less than ten beats of nystagmus and a duration of nystagmus of eight or less seconds after the leftward SCPNT, suggesting a possible bilateral vestibular hyporesponsiveness.

- DVA results and duration of nystagmus after the modified SCPNT results had been combined

There were three children who exhibited both a DVA score of more than two lines and a duration of nystagmus of less than eight seconds (when turned both to the left and to the right). This suggests that the prevalence of bilateral vestibular hyporesponsiveness in the hearing-impaired sample is 9.7%. An increased DVA score and hyporesponsiveness as determined by the duration of the nystagmus were found to be associated (Fisher's exact test p=0.018) (see Table 15). The odds ratio (OR) for those with a DVA score of greater than two having a decreased duration of nystagmus was 18.8 (CI 1.9–186.4), which was significant (a value of 1 was not included in the CI values). This means that the chances of having poor dynamic visual acuity were 18.8 times higher in children with reduced bilateral vestibular responsiveness. The sensitivity of the test of having less than eight seconds duration of nystagmus in predicting reduced dynamic visual acuity was 0.6 (CI=0.17–0.92) and the specificity was 0.93 (CI=0.74–0.99).

Table 15: DVA score and duration of nystagmus after rotations to the left (N=32)

		Left vestibular responsiveness					Right vestibular responsiveness		
		Duration of nystagmus					Duration of nystagmus		
		≤8sec (Abn)	≥8sec (Nor)	Total			≤8sec (Abn)	≥8sec (Nor)	Total
DVA score	>2 (Abn)	3	2	5	DVA score	>2 (Abn)	3	1	4
	≤2 (Nor)	2	25	27		≤2 (Nor)	1	25	26
Total		5	27	32	Total		4	26	30

Fisher's exact test p=0.018 OR=18.8 (CI 1.9–186.4)

Nor = Normal

Abn = Abnormal

- Relationship of DVA and number of beats of nystagmus in ten seconds

There were four participants who exhibited both a DVA score of more than two lines and less than ten beats of nystagmus after rotations to the left and right. This is a prevalence of 12.5% (Table 16).

Table 16: DVA score and number of beats of nystagmus in ten seconds after rotations to the left and right (N=32-30)

		Left vestibular responsiveness: Number of beats/10sec after rotation to the left (N=32)			Right vestibular responsiveness: Number of beats/10sec after rotation to the right (N=30)		
		<10 (Abn)	>10 (Nor)	Total	<10 (Abn)	>10 (Nor)	Total
DVA score	>2 (Abn)	4	1	5	4	1	5
	≤2(Nor)	7	20	27	6	19	25
	Total	11	21	32	10	20	30

Nor = Normal

Abn = Abnormal

The one-sided Fisher's exact test indicated that less than ten beats of nystagmus in ten seconds and a DVA score of more than two were found to be associated ($p=0.037$). The OR was 11.43 and this was significant (CI 1.1–120.4). The sensitivity was 0.8 (CI 0.29–0.99) and the specificity was 0.74 (CI 0.54–0.88).

4.2.4 Comparison of M-ABC-2 in participants with SNHL with reduced vestibular responsiveness and an increased DVA score

The Shapiro-Wilk test for normality indicated that the M-ABC-2 total standard scores for all participants with SNHL were not normally distributed (0.404, $df=5$, $p=0.044$). In addition, the number of children with an increased DVA score and reduced duration of nystagmus was low (Lachenicht, 2002a). Consequently, the Mann-Whitney U-test was used rather than a t-test to compare the rank ordering of the two sets of scores (Lachenicht, 2002a).

In every case, the participants with SNHL and with an increased DVA score scored less on all the components of the M-ABC-2 than the participants with SNHL and normal DVA scores (Table 17). This difference was greatest in the balance component.

Table 17: Means, standard deviations and Mann-Whitney U-statistics of the different components of the M-ABC-2 in participants with SNHL with normal and increased DVA scores (N=32)

Standard scores	DVA score	N	Mean	Standard deviation	Mean rank	Sum of ranks	Mann-Whitney-U	Z	p value
Total MABC-2	≤2 (Nor)	27	8.2	3	18.67	504	9	-3.052	0.002
	>2 (Abn)	5	3.4	1.5	4.8	24			
	Total	32							
Manual dexterity	≤2 (Nor)	27	8.9	2.5	18.2	491.5	21.5	-2.41	0.016
	>2 (Abn)	5	5.6	2.1	7.3	36.5			
	Total	32							
Aiming and catching	≤2 (Nor)	27	10.2	3.1	17.91	483.5	29.5	-1.99	0.047
	>2 (Abn)	5	7	2.8	8.9	44.5			
	Total	32							
Balance	≤2 (Nor)	27	7.4	3.9	18.61	502.5	10.5	-2.978	0.003
	>2 (Abn)	5	2	1.2	5.1	25.5			
	Total	32							

Nor = Normal

Abn = Abnormal

There was no significant difference in the rank ordering of the scores of the M-ABC-2 in participants with reduced duration of nystagmus and those with normal duration of nystagmus after rotations to the left (Table 18).

Table 18: The means, standard deviations of the standard scores and the Mann-Whitney U-statistics of the different components of the M-ABC-2 in participants with SNHL with reduced duration and normal duration of nystagmus after rotations to the left (N=32)

Standard scores	Duration of nystagmus	N	Mean	Standard deviation	Mean rank	Sum of ranks	Mann-Whitney-U	Z	p value
Total MABC-2	>8 (Nor)	27	7.8	3.3	17.56	474	39	-1.487	0.137
	≤8 (Abn)	5	5.4	2.3	10.8	54			
	Total	32							
Manual dexterity	>8 (Nor)	27	8.6	2.6	17.41	470	43	-1.283	0.199
	≤8 (Abn)	5	6.8	3.1	11.6	58			
	Total	32							
Aiming and catching	>8 (Nor)	27	10	2.9	17.09	461.5	51.5	-0.838	0.402
	≤8 (Abn)	5	8.4	3.5	13.3	66.5			
	Total	32							
Balance	>8 (Nor)	27	27	7	17.37	469	44	-1.228	0.22
	≤8 (Abn)	5	5	4.4	11.8	59			
	Total	32							

Nor = Normal

Abn = Abnormal

Table 19: Means and standard deviations of the different components of the M-ABC-2 in participants with SNHL with less than ten beats and ten or more beats of nystagmus in ten seconds after rotations to the left (N=32)

Standard scores	Beats/ 10 sec	N	Mean	Standard deviation	Mean rank	Sum of ranks	Mann-Whitney-U	Z	p value
Total MABC-2	≥10 (Nor)	21	8.3	3.2	18.83	395.5	66.5	-1.955	0.051
	<10 (Abn)	11	5.8	2.9	12.05	132.5			
	Total	32							
Manual dexterity	≥10 (Nor)	21	9.2	2.3	19.48	409	53	-2.503	0.021
	<10 (Abn)	11	6.6	2.7	10.82	119			
	Total	32							
Aiming and catching	>10 (Nor)	21	10.3	3	18.29	384	78	-1.501	0.133
	<10 (Abn)	11	8.6	2.8	13.09	144			
	Total	32							
Balance	≥10 (Nor)	21	7.1	4.1	17.79	373.5	88.5	-1.078	0.281
	<10 (Abn)	11	5.6	4	14.05	154.5			
	Total	32							

Nor = Normal

Abn = Abnormal

Participants with less than ten beats of nystagmus in ten seconds after rotations to the left scored significantly lower in the manual dexterity component than participants with more than ten beats of nystagmus in ten seconds ($p=0.021$) (Table 19). No significant difference was found in the other components of the M-ABC-2 in participants with less than ten beats of nystagmus in ten seconds after rotations to the left.

In summary, there was a significant difference in the rank ordering of all components of the M-ABC-2 between the participants with SNHL with normal and increased DVA scores. However, no difference was found on any component between the participants with SNHL and with reduced duration of nystagmus and normal duration of nystagmus. Participants with less than ten beats of nystagmus per ten seconds

showed a significant difference in the manual dexterity component in comparison to participants with more than ten beats of nystagmus in ten seconds.

Table 20: Prevalence of impairments in participants with SNHL

Poor dynamic visual acuity (DVA score>2)	15.6%
Left hyporesponsiveness (duration \leq 8 secs)	5.6%
Right hyporesponsiveness (duration \leq 8 secs)	3.3%
Bilateral vestibular hyporesponsiveness (duration \leq 8 secs)	10%
Left hyporesponsiveness (<10 beats/10 secs)	7.8%
Right hyporesponsiveness (<10 beats/10 secs)	6.7%
Bilateral vestibular hyporesponsiveness (<10 beats/10 secs)	26.6%
Both duration \leq 8 secs and beats/10secs	15.6%
Both poor DVA/decreased duration	9.7%
Both Poor DVA/decreased beats/10secs	12.5%
Both poor DVA/Abnormal M-ABC-2	15.6%

The Fisher's exact test indicated that an abnormal DVA score and the duration of nystagmus less than eight seconds and less than ten beats of nystagmus in ten seconds (signs of vestibular hyporesponsiveness) were all significantly associated with each other. However, in the current study, there were children who exhibited one sign and not the others.

4.2.5 Comparison of DVA score in participants with SNHL and normal-hearing participants

The t-test indicated that there was no significant difference in the ages of the two groups of children (t-value=-0.42, p-value=0.886). Similarly, there was no association between SNHL and gender (chi-sq=0.063, df=1, p=0.802).

The Fisher's exact test indicated that a DVA score of more than two was associated with SNHL (p=0.026 for one-sided Fisher's exact test) (Table 21). As there were no normal-hearing children with an abnormal DVA score an OR could not be calculated.

Table 21: DVA score of participants with SNHL and of normal-hearing participants (N=64)

	DVA score	>2 (Abn)	≤2 (Nor)	Total
Group	SNHL	5	27	32
	Normal hearing	0	32	32
Total		5	59	64

Nor = Normal

Abn = Abnormal

4.2.6 Comparison of vestibular hyporesponsiveness in participants with SNHL and normal-hearing participants

Ten percent of participants with SNHL presented with reduced responsiveness after the SCPNT bilaterally when duration of nystagmus was used as criterion for vestibular hyporesponsiveness. No normal-hearing participants had a reduced duration of nystagmus after the modified SCPNT in both directions, suggesting that no normal-hearing participant had reduced vestibular responsiveness when duration of nystagmus was used as criterion.

When the number of beats of nystagmus in ten seconds was used to determine vestibular hyporesponsiveness, 26.6% of participants with SNHL had bilaterally reduced vestibular responsiveness. No participants of the normal-hearing group had bilaterally reduced responsiveness when the number of beats of nystagmus in ten seconds was used as criterion (Figure 5 & Table 22). Less than ten beats of nystagmus in ten seconds is strongly associated with SNHL ($p < 0.0001$ one-sided Fisher's exact).

Two normal-hearing participants had nine beats of nystagmus in ten seconds and one had six beats of nystagmus in ten seconds after rotations to the right (Figure 6 & Table 22). This translates into a prevalence of 9.38% of possible right unilateral vestibular hyporesponsiveness.

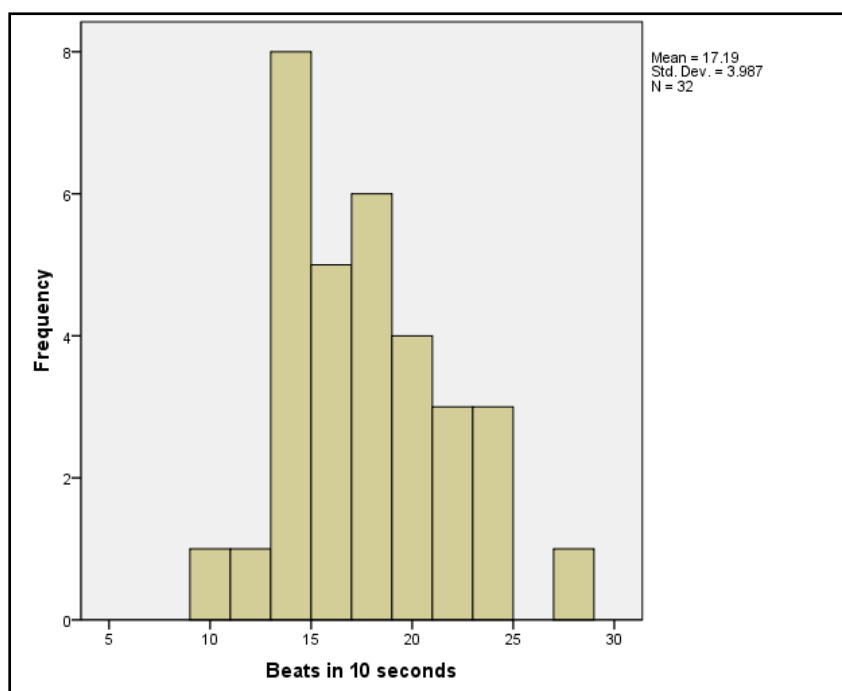


Figure 5: Number of beats of nystagmus in ten seconds after rotations to the left in the normal-hearing group (N=32)

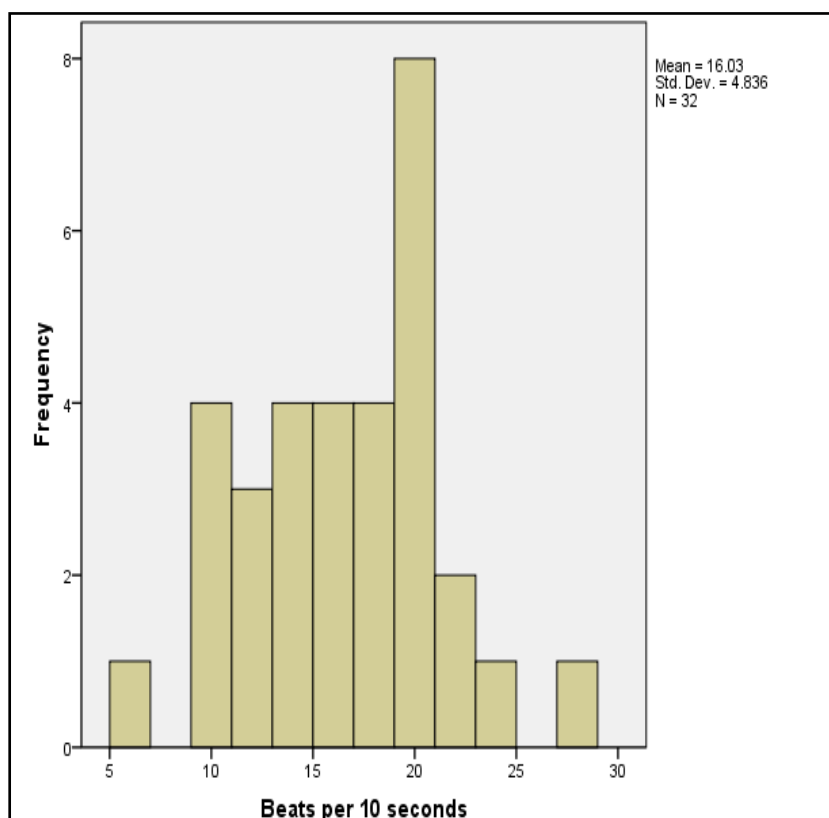


Figure 6: Number of beats of nystagmus in 10 seconds after rotation to the right in the normal-hearing group (N=32)

Table 22: Number of beats in ten seconds in SNHL and in normal-hearing groups after rotations to the left and right (N=64)

	Left vestibular responsiveness				Right vestibular responsiveness		
Group	<10 (Abn)	>10 (Nor)	Total	Group	<10 (Abn)	>10 (Nor)	Total
SNHL	11	21	32	SNHL	10	20	30
				Refused (SNHL)			2
Normal hearing	0	32	32	Normal hearing	3	29	32
Total	11	53	64	Total	13	49	64

Nor = Normal, Abn = Abnormal

Table 23: Means and standard deviations of number of beats of nystagmus in ten seconds in participants with SNHL and in normal-hearing participants (N=32–30)

	Group	N	Mean	Standard deviation	Standard error mean	p-value
LSCPNT beats/10 sec	SNHL	32	11.50	6.027	1.065	0.000
	Normal hearing	32	17.19	3.987	0.705	
RSCPNT beats/10 sec	SNHL	30	11.70	6.814	1.244	0.005
	Normal hearing	32	16.03	4.836	0.855	

LSCPNT beats/10 sec = Number of beats of nystagmus in 10 seconds after modified SCPNT to the left

RSCPNT beats/10 sec = Number of beats of nystagmus in 10 seconds after modified SCPNT to the right

The two groups were equivalent with regard to age and gender but SNHL was associated with an increased DVA score, duration of nystagmus of eight seconds or less, and less than ten beats of nystagmus in ten seconds after the modified SCPNT. In addition, the number of beats and duration of nystagmus after stimulation was significantly different between the two groups. Although the same participants did not

exhibit both a DVA score of more than two and a duration of nystagmus of less than eight seconds, there was an equivalent number of participants with reduced duration of nystagmus and an increased DVA score. Both were associated with SNHL ($p=0.026$ for one-sided Fisher's exact test).

4.2.7 Comparison of M-ABC-2 in participants with SNHL and normal-hearing participants

The participants with SNHL scored lower than their normal-hearing counterparts on all the components of the M-ABC-2, with the greatest difference being in the balance component, followed by the overall score (Table 24).

Table 24: Differences between the means of the different components of the M-ABC-2 in participants with SNHL and their normal-hearing counterparts (N=64)

Measurement	Group	N	Mean	Standard deviation	Standard error mean
Total MABC-2	Normal hearing	32	11.4	2.0	0.4
	SNHL	32	7.4	3.3	0.6
	<i>Difference</i>		<i>4.0</i>		
Manual dexterity	Normal hearing	32	10.1	2.1	0.4
	SNHL	32	8.3	2.7	0.5
	<i>Difference</i>		<i>1.8</i>		
Aiming and catching	Normal hearing	32	11.8	2.0	0.3
	SNHL	32	9.7	3.0	0.4
	<i>Difference</i>		<i>2.1</i>		
Balance	Normal hearing	32	12.1	2.7	0.5
	SNHL	32	6.6	4.1	0.7
	<i>Difference</i>		<i>5.6</i>		

The total standard scores on the M-ABC-2 of the two groups are depicted in Figure 7. The mean of the participants with SNHL was 7.44 (SD 3.3) and 11.44 (SD 2.0) for the participants with normal hearing.

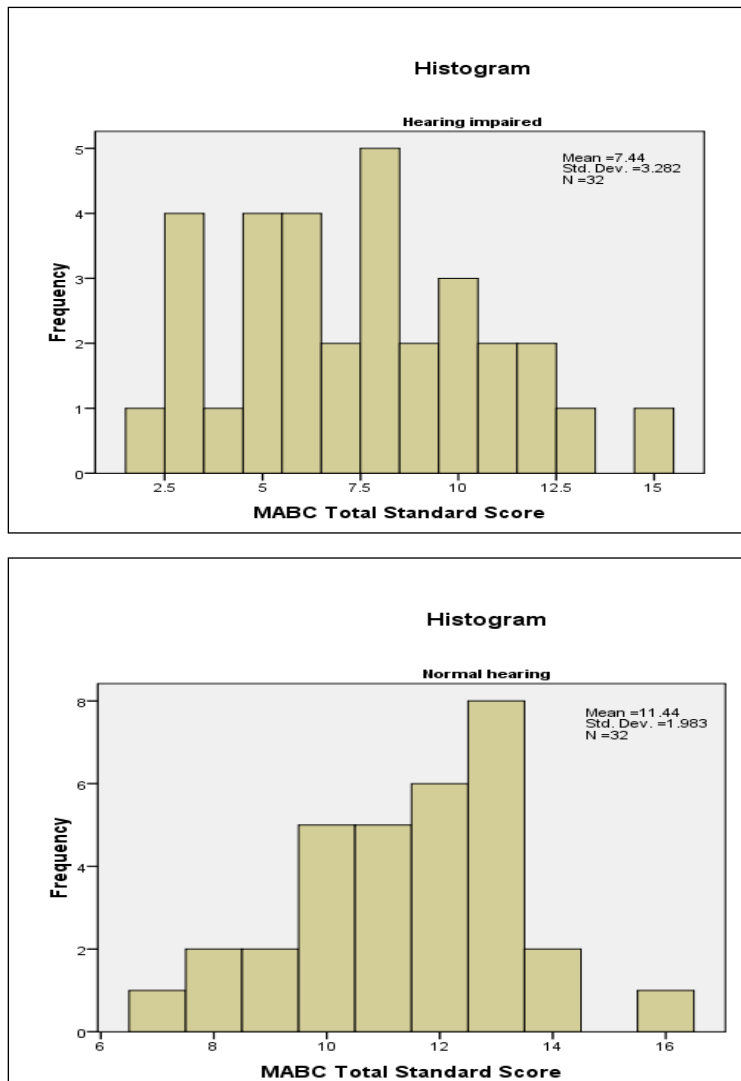


Figure 7: Histograms of the total standard scores of the M-ABC-2 in participants with SNHL and normal-hearing participants

Results of the Shapiro-Wilk test indicated that almost all scores on the sub-components of the M-ABC-2 of the participants with SNHL and normal hearing were not normally distributed (Table 25), therefore the Mann-Whitney U-test was used to compare the rank ordering of the two groups (Lachenicht, 2002a).

Table 25: The results of the Shapiro-Wilk test for normality

Group		Shapiro-Wilk		
		Statistic	Df	Significance
Total MABC	SNHL	0.970	32	0.507
	Normal hearing	0.962	32	0.318
Manual dexterity	SNHL	0.923	32	0.026
	Normal hearing	0.949	32	0.135
Aiming and catching	SNHL	0.940	32	0.073
	Normal hearing	0.935	32	0.053
Balance	SNHL	0.932	32	0.045
	Normal hearing	0.852	32	0.000

There is a significant difference in the rank ordering of all the components of the M-ABC-2 between the group with SNHL and the group with normal hearing (Table 26). The largest difference was found in the balance component and the total test score.

Table 26: Comparison of the different components of the M-ABC-2 in the group with SNHL and the group with normal hearing (N=64)

Standard scores	Group	N	Mean rank	Sum of ranks	Mann-Whitney-U	Z	p value
Total MABC-2	Normal hearing	32	43.55	1 393.50	158.500	-4.771	0.000
	SNHL	32	21.45	686.50			
	Total	64					
Manual dexterity	Normal hearing	32	38.38	1 228.00	324.000	-2.553	0.011
	SNHL	32	26.63	852.00			
	Total	64					
Aiming and catching	Normal hearing	32	38.92	1 245.50	306.500	-2.800	0.005
	SNHL	32	26.08	834.50			
	Total	64					
Balance	Normal hearing	32	44.11	1 411.50	140.500	-5.047	0.000
	SNHL	32	20.89	668.50			
	Total	64					

4.2.8 Predictors of performance on the M-ABC-2 in participants with SNHL

Age and dummy variables to represent gender, presence of reduced duration of nystagmus after rotations to the left and right, profound hearing impairment (but not the other levels of SNHL), presence of a cochlear implant and presence of an increased DVA score were included in the forward stepwise model. The only variables retained by the forward stepwise model were the presence of an increased DVA score and presence of profound hearing loss (Table 27). The adjusted r^2 of this model was 0.33, which implies that 33% of the variance in the M-ABC-2 score could be attributed to the variables retained in the equation. There was one participant whose residual score was larger than two 2 standard residuals, and this participant

was excluded from the analysis. The adjusted r^2 of the final model was then 0.41, which implies that age, presence of a profound hearing loss and an increased DVA score collectively accounted for 41% of the variance.

Table 27: Predictors of the M-ABC-2 score results of the forward stepwise regression

	B-weight	Standard error	t(27)	p-level	Adjusted r^2 added by each variable
Intercept	7.7	1.95	3.92	0.001	
Increased DVA score	-4.4	1.24	-3.55	0.001	.30
Profound deafness	-3.0	1.27	-2.35	0.027	.07

Note that *B-weight* is the coefficient attached to the variable under consideration.

4.2.9 Predictors of performance on the M-ABC-2 in participants with SNHL and normal hearing

In order to determine the predictors of the M-ABC-2 in the entire group, age, gender, reduced duration of nystagmus after rotation to the left and right, presence of SNHL and presence of an increased DVA score were included in the model which was applied to both hearing-impaired and normal-hearing children. Age, gender and reduced duration of nystagmus after rotations were excluded from the forward stepwise model. The adjusted r^2 of this model was 0.479, which implies that 48% of the variance in the M-ABC-2 score could be attributed to the variables retained in the equation, i.e. presence of SNHL and an increased DVA score. There were two participants whose residual scores, i.e. the difference between the predicted and the observed M-ABC-2 scores were greater than two standard residuals and these were excluded from the analysis. The adjusted r^2 of the final model was then 0.54, which then accounted for 54% of the variance.

A child with SNHL will score 3.3 points less on the M-ABC-2 than a child with normal hearing. In addition, a child with an increased DVA score would score 4.7 points less on the M-ABC-2 than a child with a normal DVA score (Table 28).

Table 28: Retained variables of the forward stepwise regression

	Unstandardised coefficients		T	Significance
	B-weight	Standard error		
Constant	11.44	0.39	26.7	0.000
SNHL	-3.32	0.59	-5.1	0.000
DVA score >2 (Abn)	-4.72	1.01	-4.1	0.000

Abn = Abnormal

Note that *B-weight* is the coefficient attached to the variable under consideration.

The total test scores ranged between less than 29 to 108 with the norm between 78 and 81. As the total test scores of the participants without SNHL and those with a mild to moderate SNHL appeared to be similar, the Kruskal-Wallis test, the non-parametric equivalent of the one-way ANOVA, was used to compare the rank ordering of the scores of these three groups (see Figure 8).

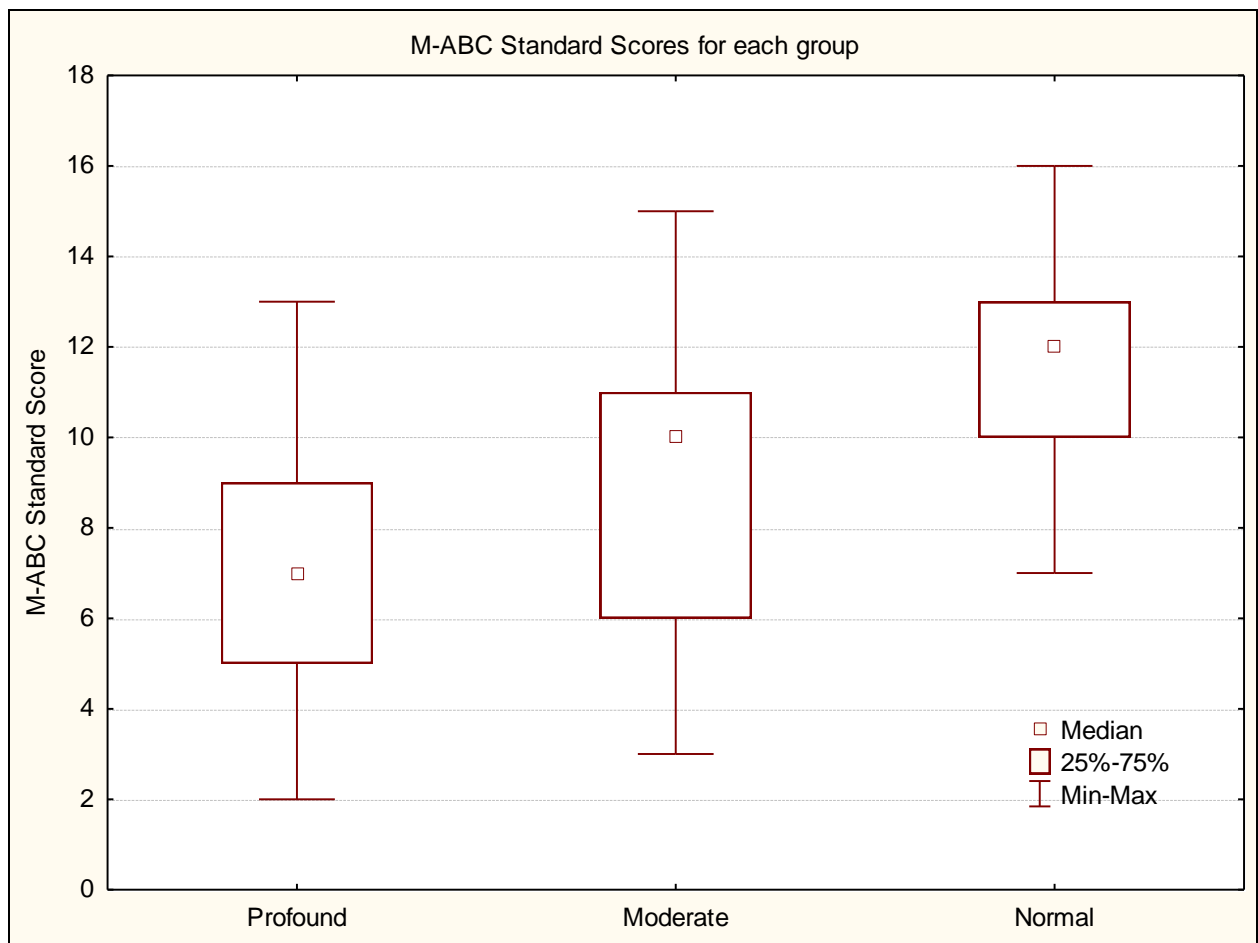


Figure 8: The difference in means between participants with profound and moderate SNHL and normal-hearing participants (N=64)

The Kruskal-Wallis test indicated that there was a significant difference in the rank ordering ($H=24.69$, $DF=2$, $N=64$, $p<0.001$) of the M-ABC-2, and post-hoc analysis indicated that there was a difference between the participants with profound SNHL and the normal-hearing participants ($p<.001$). The ranking of the scores of the participants with moderate SNHL lay between those of the other two groups and were not significantly different to either group.

4.3 Summary of results

According to the results of the study –

- SNHL was associated with an increased DVA score, duration of nystagmus of eight seconds or less, and less than ten beats of nystagmus in ten seconds after the modified SCPNT. In addition, the number of beats and duration of nystagmus after stimulation differed significantly between children with and those without hearing loss. Participants with SNHL and increased DVA scores scored significantly lower than participants with SNHL and normal DVA scores on the M-ABC-2. No difference was found on any component of the M-ABC-2 between the participants with SNHL and reduced duration of nystagmus and participants with SNHL and normal duration of nystagmus.
- Participants with less than ten beats of nystagmus per ten seconds showed a significant difference in the manual dexterity component of the M-ABC-2 in comparison to participants with SNHL and more than ten beats of nystagmus in ten seconds.
- The group with SNHL scored significantly lower on all components of the M-ABC-2 than the normal-hearing group. The largest difference was found in the balance component and the total test score.
- An increased DVA score, age and the presence of profound hearing loss were the variables that were retained by the forward stepwise model to predict performance on the M-ABC-2 in participants with SNHL. The variance in the M-ABC-2 score in the SNHL group and normal-hearing group could be attributed to the variables retained by the forward stepwise model, i.e. presence of SNHL and an increased DVA score.
- A significant difference in performance on the M-ABC-2 was found between the participants with profound SNHL and the normal-hearing participants. The participants with moderate SNHL lay between the group with profound SNHL and the normal-hearing group and were not significantly different to either group. See Table 29 for summary of the results.

Table 29: Summary of number and percentages of participants with impairment on the different tests (N=32–30–32)

	N	Abn DVA	Abn SCPNT dur bilat	Abn SCPNT # bts bilat	Abn MABC 2	Abn DVA & SCPNT dur bilat	Abn DVA & SCPNT # bts bilat	Abn DVA & MABC 2	Abn DVA & MABC 2 & SCPNT dur bilat	Abn DVA & MABC 2 & SCPNT #bts bilat
Profound SNHL	26 (81.3%)	5 (15.6%)	3 (10%)	8 (26.6%)	19 (59.4%)	3 (10%)	3 (10%)	5 (15.6%)	3 (10%)	3 (10%)
Severe SNHL	1(3.1%)	0	0	0	0	0	0	0	0	0
Moderate SNHL	3(9.4%)	0	0	2	1	0	0	0	0	0
Slight SNHL	1(3.1%)	0	0	0	1	0	0	0	0	0
Normal limits/ Discrete high frequency hearing loss	1(3.1%)	0	0	0	0	0	0	0	0	0
Normal hearing	32 (100%)	0	0	3 (9.4%)	0	0	0	0	0	0

Abn DVA = Abnormal DVA (>2)

Abn SCPNT Dur Bilat = Reduced duration of nystagmus bilaterally (≤ 8 secs)

Abn SCPNT # bts Bilat = Reduced number of beats of nystagmus bilaterally (<10 beats/10 secs)

Abn MABC2 = Abnormal M-ABC-2 (total standard score <6)

Note that N=30 for participants with SNHL that assent to the modified SCPNT to both sides.

Results of abnormal scores by participant on the different tests are given in Table 30.

Table 30: Abnormal results of participants with SNHL on individual tests

Participant	Abn MABC	Abn DVA	SCPNT Abn dur bilat	SCPNT Abn dur unilat	SCPNT Abn # beats bilat	SCPNT Abn # beats unilat	Refused SCPNT to right
1	*						
28	*	*	*		*		
35	*					*	Refused R
57	*	*	*		*		
3	*				*		
39	*					*	
6	*				*		
42	*						
64						*	
31	*				*		
40	*				*		
49	*				*		
11	*	*				*	Refused R
18	*	*	*		*		
25	*						
27	*	*			*		
37	*						
24	*						
14						*	
26	*			*	*		
23	*						
47	*						
15	*						

Abn MABC	=	Abnormal M-ABC-2
Abn DVA	=	Abnormal DVA score
SCPNT Abn dur bilat	=	Abnormal duration of nystagmus bilaterally
SCPNT Abn dur unilat	=	Abnormal duration of nystagmus unilaterally
SCPNT Abn # beats bilat	=	Abnormal number of beats of nystagmus bilaterally
SCPNT Abn # beats unilat	=	Abnormal number of beats of nystagmus unilaterally

5 DISCUSSION

In this chapter, a comparison with the literature will be presented followed by the implications of the results obtained in the current study. The first section gives a short summary of the main findings.

5.1 Short summary of main findings:

The main findings of the study will be discussed in detail; however, the points below highlight the most pertinent findings:

In the sample of participants with SNHL:

- of the hearing-impaired participants, 15.6% had abnormal results on the DVA test, suggesting that these children have decreased visual acuity when the head is moving;
- abnormal DVA scores are related to increasing severity of hearing loss;
- the modified SCPNT demonstrated reduced duration of nystagmus bilaterally in 10% of participants with bilateral SNHL;
- duration of nystagmus as induced by SCPNT is not related to performance on the M-ABC-2;
- the modified SCPNT demonstrated a reduced number of beats bilaterally in 26% of participants with bilateral SNHL;
- the DVA and M-ABC-2 findings combined would suggest reduced vestibular function in a subset of 15.6% of the participants with SNHL;
- of the participants with SNHL, 65.6% had abnormal M-ABC-2 scores of which 86.44% were profoundly deaf; and
- predictors of motor performance were age, increasing severity of hearing loss and reduced DVA.

In a sub-set (N=5) of participants with SNHL hearing loss and abnormal DVA scores:

- abnormal total test scores were found on the M-ABC-2 in 100% of the subset sample; and
- in particular the balance component on the M-ABC-2 was affected in 100% of the subset sample.

In a sub-set (N=11) of participants with a reduced number of beats of nystagmus in ten seconds on the modified SCPNT, manual dexterity was affected in 37.5%.

In a comparison of participants with SNHL and those with no hearing impairment:

- significant differences were found between the duration of nystagmus as a result of the modified SCPNT with shorter duration of nystagmus in the SNHL group;
- significant differences were found between the number of beats of nystagmus in ten seconds as a result of the modified SCPNT with less beats of nystagmus in the SNHL group;
- the presence of hearing loss was associated with a reduction in overall scores on M-ABC-2;
- the presence of hearing loss was associated with a reduction in scores on the balance component of the M-ABC-2; and
- the presence of hearing loss and abnormal DVA scores were associated with poor M-ABC-2 scores.

5.2 Performance of the measurement instruments

5.2.1 The M-ABC-2

In a study by Chow and Henderson (2003), the ICC for intra-rater reliability for the M-ABC-2 ranged between 0.79 and 0.93. Similar results were obtained in the current study with ICC of 0.86 for intra-rater reliability on the total test score. Chow and Henderson 2003, in their study, found that the ICC for inter-rater reliability ranged between 0.94 and 1.00. The ICC for the current study for the total test score was within the same range, with ICC 0.99. The inter-rater and intra-rater reliability on the M-ABC-2 in the current study was therefore adequate.

5.2.2 DVA test

As indicated in Chapter 2, the DVA test is a reliable and valid measure of gaze stability (Rine & Braswell, 2003). Rine & Braswell (2003) found that the test-retest reliability for SVA and horizontal DVA was excellent with ICC=0.94 and 0.84 respectively as well as the inter-rater reliability with ICC for SVA=0.93 and for horizontal DVA=0.88. Sensitivity, specificity as well as positive and negative predictive values for BVH were 100%, regardless of age (ANOVA $p=0.007$) (Rine & Braswell, 2003). However, in the current study, the intra-rater reliability of the DVA score was low with ICC=0.58. It is suggested that the variation in performance from one occasion to the next may be ascribed to fluctuation of the participant's

performance from one day to the next rather than to inaccuracy in measurement. The concurrent validity was evident in that associations were found when expected (e.g. vestibular hyporesponsiveness and DVA abnormality) and known groups performed differently (difference between results of SNHL and children with normal hearing). Due to practical constraints, all participants were tested after school hours. The younger participants found it difficult to concentrate because they were tired, especially because they were tested during their afternoon rest period. It is possible that exhaustion as a result of physical activities could lead to lack of concentration, which in turn could result in difficulty to perform optimally. Another reason for participants not performing optimally on both occasions might have been the fact that some of the participants were from rural areas with limited or no access to specialist medical care. It is possible that some of these participants might have had other problems such as ADHD, other neurological conditions or eye problems that have not yet been diagnosed by a specialist.

5.2.3 The SCPNT

The SCPNT is a measure of the responsiveness of the horizontal SCC. Several studies confirmed the reliability of the SCPNT. Morrison and Sublett (1983) found that inter-rater and intra-rater reliability was significant for learning disabled children ($r=0.72$, $p=0.000$ and $r=0.67$, $p=0.000$ respectively). Kimball (1981) retested 63 typically developing children two and a half years after the initial testing and found a test-retest reliability coefficient of 0.80. Ayres (1975) found retest reliability to be 0.83. In the current study, the intra-rater and inter-rater ICC were significantly higher than 0.9, which is higher than in the previous studies. The reason for higher ICC might be that, in the current study, the children sat on an office chair that supported the trunk. The neck was kept in 30° of flexion by means of a neck brace. The children did not lose their balance as a result of the rotations and the head posture ensured maximum stimulation of the horizontal SCC. When the test was repeated a week later, the children were positioned in the same posture as with for the first test. The abovementioned studies did not control for fixation suppression of nystagmus or head and trunk posture. In the classic SCPNT, children sit on a board that could rotate with no trunk support. The head was positioned in 30° of flexion, but there was a good possibility that the child might not have maintained this position during rotations leading to reduced stimulation of the horizontal SCC. Frenzel lenses were

not used in the earlier studies. Children were instructed to look at a white wall in an attempt to reduce fixation. The use of Frenzel lenses revealed nystagmus, which might otherwise have been suppressed by fixation. The magnifying properties of the Frenzel lenses also made the observation of nystagmus easier. Recording of nystagmus by means of a camcorder enabled the investigator to do observations more than once. It was therefore less likely that beats of nystagmus were missed. It is important to control the head and trunk posture of the child and to prevent fixation (with the use of Frenzel lenses) that can suppress nystagmus to obtain accurate results with the SCPNT.

5.3 Prevalence rates of impairments

5.3.1 Decreased DVA

Of the 32 participants with SNHL who were tested during the second phase of the study, 15.6 % had a difference of more than two lines on the DVA test. It has been suggested that this is an indication of poor dynamic visual acuity due to VH (Rine & Braswell, 2003). Dannenbaum, Paquet, Hakim-Zadeh and Feldman (2005) reported that adult patients with unilateral vestibular loss due to surgical resection of an acoustic neuroma had DVA scores with horizontal head movements of between two and eight lines. Longridge and Mallinson (1987) found a significant correlation ($p < 0.05$) between abnormal DVA scores with horizontal head movement and reduced caloric responses in adults. No literature could be found on the prevalence of poor dynamic visual acuity in children with SNHL. Acquired oscillopsia is a symptom of vestibular hypofunction due to gaze instability. Poor dynamic visual acuity has a major impact on the quality of life of adults. It leads to decreased levels of activity, avoidance of driving and limited social interactions (Herdman et al., 2007). Adults with poor dynamic visual acuity also have difficulties with reading, especially when it is accompanied by head movement (Herdman & Clendaniel, 2007). Although it is not likely for children with congenital or early acquired vestibular dysfunction to experience oscillopsia (Longridge & Mallinson, 1987), they may present with poor dynamic visual acuity as a result of gaze instability due to reduced vestibular function.

We can postulate that poor dynamic visual acuity can have a major impact on the development of children. If a child is not able to hold the image of an object steady

on the fovea, it can play a role in the child's ability in learning to read. Reading difficulties may in turn result in learning difficulties and this may have a major impact on the education of children with poor dynamic visual acuity (Braswell & Rine, 2006a). Braswell and Rine (2006a) found that children with BVH scored lower on reading acuity tests than children with normal vestibular function. Reading acuity scores correlated with dynamic and not static visual acuity scores. Poor scholastic performance and reduced levels of educational performance might have an influence on future earning potential and overall quality of life.

It can be argued that children with poor dynamic visual acuity might have difficulties with other normal childhood activities like crossing a street. In an activity like this, a lot of head movements are required and the ability to judge distance and speed is essential. This can become a dangerous activity because head movements can lead to poor dynamic visual acuity. Poor dynamic visual acuity might also affect the social and emotional development of children, because they might feel that they do not perform adequately.

It can be postulated that poor dynamic visual acuity can also have an effect on the child's ability to take part in sport and other recreational activities. Smooth pursuit eye movements are used to maintain moving targets on the fovea of the retina (Tusa, 2007). With VOR deficits, the image of the moving target cannot stay on the fovea (Tusa, 2007). With poor dynamic visual acuity, children can have difficulty in following moving objects like a ball coming towards them. Children with gaze instability might have difficulties with catching or hitting a ball, as it is extremely difficult to follow a moving object with the eyes, especially when the child is running causing even more head movement. This can even be more challenging if the child has difficulty in maintaining balance as is suggested by the current study.

None of the participants with normal hearing who took part in the current study had reduced dynamic visual acuity as determined by the DVA test. The prevalence of reduced dynamic visual acuity is therefore associated with SNHL.

As this study indicated that at least one in eight children with SNHL might have poor dynamic visual acuity, it is suggested that routine screening for decreased dynamic visual acuity be included in the assessment of any child with SNHL. Gaze stability exercises have been used with great success in adults with poor dynamic visual

acuity in the recovery of gaze stability (Herdman et al., 2007). Such therapy might have similar effects on children with poor dynamic visual acuity. This type of therapy falls within the scope of physiotherapy and it is an available and feasible form of intervention in a developing country context.

5.3.2 Vestibular hyporesponsiveness

The SCPNT gives an indication of the sensitivity of the horizontal SCC. The number of hearing-impaired participants with reduced duration of nystagmus after the modified SCPNT was more than one in eight. In general, the prevalence of reduced sensitivity of the horizontal SCC in children with SNHL was lower in the current study when the duration of nystagmus was used as a criterion of vestibular hyporesponsiveness than what was found for VH in other studies (Arnvig, 1955; Crowe & Horak, 1988; Horak et al., 1987; Rosenbult et al., 1960). According to Arnvig (1955), who used caloric testing, the prevalence of VH in congenital SNHL is 34% and in acquired SNHL up to 82%. Horak et al. (1987) and Crowe and Horak (1988) who used rotary chair testing, found that 67% of children with SNHL of mixed aetiologies also have VH. These studies all used either caloric irrigation or rotary chair testing as stimulation of the vestibular system, and nystagmus was recorded by an ENG. These tests are the gold standard methods to evaluate the function of the SCC (Schubert & Minor, 2004). Although every effort was made to make the modified SCPNT as accurate as possible, it must be acknowledged that the caloric and rotary chair tests are more accurate than the modified SCPNT because, with the modified SCPNT, the duration of nystagmus is measured, and with the gold standard tests, the speed of the slow phase of the nystagmus is measured (Fife et al., 2000). In the abovementioned studies, participants with congenital and acquired SNHL were included. In the current study, although it was not the intention, the majority of the participants, namely 31 of the 32, had congenital SNHL, while the remaining participant's reason for hearing loss was unknown. Selz et al. (1996) reported that children with congenital SNHL showed reduced vestibular function to a lesser degree than children with acquired SNHL. It is possible that bacterial infections, such as meningitis, can lead to more widespread damage than damage to the cochlea only (Aneja & Aggarwal, 1997). The pathology resulting in SNHL can therefore have an effect on vestibular function.

When the number of beats of nystagmus in ten seconds after the modified SCPNT was used as a criterion for vestibular hyporesponsiveness, 34.4% of the participants with SNHL had less than ten beats of nystagmus in ten seconds. The number of beats of nystagmus in ten seconds was counted to get an indication of the speed of the nystagmus. This finding is remarkably similar to the rate of VH in children with congenital SNHL, namely 34%, in the study of Arnvig (1950).

When less than ten beats of nystagmus in ten seconds was used as a criterion for VH, no normal-hearing participants with less than ten beats of nystagmus in ten seconds after rotations to the left was found. However, there were three normal-hearing participants with less than ten beats of nystagmus after ten rotations to the right, suggesting right vestibular hyporesponsiveness. Two of these participants had nine beats and one participant had six beats of nystagmus in ten seconds. This is a prevalence of 9.4%. Other authors have found that the prevalence of VH in normal-hearing children is between 7% and 14% (Crowe and Horak 1988; Horak et al., 1987). Although participants were instructed to keep their eyes open after rotations had stopped and to look straight ahead through the Frenzel lenses, it is possible that the investigator could have missed one or two beats when nystagmus was observed because the number of beats is influenced by the position of the eye in the orbit (Tusa, 2007). Gaze in the direction of the quick phases of the nystagmus will increase the intensity of the nystagmus, but gaze in the direction of the slow phases of nystagmus will suppress the intensity of the nystagmus (Tusa, 2007). According to the health questionnaire of the participant with six beats of nystagmus, the participant had encephalitis as a young child. The *Herpes simplex* virus is a common cause of encephalitis and it is also one of the common causes of vestibular neuritis (Roos, 1999; Schubert & Minor, 2004). It is possible that this participant had damage to the right peripheral vestibular system as a result of encephalitis, leading to right UVH.

Reduced vestibular responsiveness was associated with SNHL when the criteria of eight or less beats of nystagmus as well as less than ten beats of nystagmus in ten seconds were used as an indication of vestibular hyporesponsiveness. It could therefore be argued that the stimulation to the semicircular canals of hearing-impaired children was inadequate to produce a robust response, suggesting possible hypofunction. The results of the current study confirm the findings of previous studies

that reduced vestibular responsiveness in children is associated with SNHL (Braswell & Rine, 2006a; Crowe & Horak, 1988; Horak et al., 1987; Selz et al., 1996).

5.3.3 Motor impairment

The participants with SNHL scored lower than their normal-hearing counterparts on all the components of the M-ABC-2, the greatest difference being in the balance component, followed by the total test score. Other studies have also found that children with SNHL present with motor deficits (Crowe & Horak, 1988; Horak et al., 1987; Kaga et al., 2008). The current study confirms these findings and it further suggests that balance is affected more than manual dexterity and ball skills in participants with SNHL. This is in line with results found by Horak et al. (1987) that balance is affected more than other motor skills.

It can be argued that difficulties in maintaining balance can lead to difficulties in normal childhood activities, such as playing on a jungle gym or riding a bicycle or a skateboard. Since children with affected balance may have difficulties in playing certain games that require adequate balance, they may become socially isolated.

This may indicate the need to evaluate the motor performance of children with congenital or early acquired SNHL to identify any delay of motor development as early as possible. A critical period between four and six years of age for the development of postural control was reported by Woollacott and Shumway-Cook (1990). It is therefore crucial for the development of children with SNHL and motor impairments to receive appropriate therapy within that critical period to obtain optimal functionality.

5.3.4 Association between impairments

An equal number of participants with SNHL had reduced duration of nystagmus after the SCPNT and an increased DVA score. Although the same participants did not exhibit both problems, three of the five participants with poor dynamic visual acuity also had reduced duration of nystagmus. Reduced duration of nystagmus and an increased DVA score were both associated with SNHL. Both an increased DVA score and reduced duration of nystagmus after the SCPNT were associated with less than ten beats of nystagmus after the SCPNT. These tests are all indications of reduced vestibular responsiveness of the participants. The results of the tests

indicate an association with SNHL and with each other and confirm the concurrent validity of the tests.

In every case, the participants with SNHL and an increased DVA score scored less than the participants with SNHL and normal DVA scores in every component of the M-ABC-2, with the greatest difference in the balance component. This finding suggests an association between dynamic visual acuity and motor performance. One of the main functions of the vestibular system is to stabilise the eyes when the head is moving (Angeli, 2003; Nandi & Luxon, 2008). The vestibular system is also responsible for maintenance of balance (Angeli, 2003; Nandi & Luxon, 2008). It can therefore be argued that both decreased dynamic visual acuity and poor motor performance and particularly poor balance, are a result of reduced vestibular function.

Even though the SCPNT was modified in the hope of being more accurate than the conventional test, there was surprisingly no significant difference in the rank ordering of the scores of the M-ABC-2 in participants with reduced duration of nystagmus and those with normal duration of nystagmus after the modified SCPNT. It was expected that, if the SCPNT is an indication of vestibular function, the participants with a reduced duration of nystagmus would present with poor motor performance, particularly poor balance. This was however not the case, suggesting that the SCPNT might not measure vestibular function. Results of the SCPNT might only be an indication of the responsiveness of the horizontal SCC. It was beyond the scope of the current study to correlate findings on the SCPNT with the gold standard caloric and rotary chair tests. It can be postulated that, even with reduced responsiveness of the horizontal SCC, an adequate VSR relying more on otolith input can result in normal motor performance and balance.

An interesting finding was that participants with less than ten beats of nystagmus in ten seconds after rotations scored significantly lower on the manual dexterity component of the M-ABC-2 than participants with more than ten beats of nystagmus in ten seconds. According to earlier studies (Crowe & Horak, 1988; Horak et al., 1987), balance is more often affected by VH than fine motor skills. In the current study participants had to do head movements when performing the tasks of the manual dexterity component. Furthermore, less than ten beats of nystagmus in ten seconds and a DVA score of more than two were found to be associated ($p=0.037$).

A reduced number of beats in ten seconds is an indication of reduced responsiveness of the horizontal SCC, which play a role in the VOR. Reduced responsiveness of the horizontal SCC may affect the VOR leading to poor dynamic visual acuity. The uncoupling of the eye movement and head movement will lead to gaze instability, which in turn can lead to difficulties with fine motor skills because the subject is not able to see clearly when the head is moving. It is reasonable to expect that other everyday fine motor activities, such as tying shoelaces, can become a problem due to reduced dynamic visual acuity as a result of reduced vestibular responsiveness.

5.3.5 Prediction of motor impairment

Results of the M-ABC-2 appear to correlate with increasing severity of hearing loss. Participants with profound SNHL scored poorer than participants with a lesser degree of SNHL on the M-ABC-2. The M-ABC-2 score was also lower in children with SNHL than in children with no auditory impairment, and further analysis revealed that the difference lies between profoundly deaf and normal-hearing children. The only variables retained by the forward stepwise model to predict performance on the M-ABC-2 in the entire group were the presence of an increased DVA score, the presence of profound SNHL, and age and the predicted value for a 10-year-old child who does not have profound SNHL or an increased DVA score, using the model identified in the Chapter 4, would be 10.96. This is compared to a 10-year-old child with profound SNHL and an increased DVA score whose predicted value is 3.6 (Table31).

Table 31: The predicted score of a 10-year-old child with and without profound SNHL and increased DVA score

	B-weight	Value	B-weight value		Value	B-weight value		Value	B-weight value
Normal DVA score	-4.39	0.00	0.00	Normal DVA score	0	-0.00	Increased DVA score	1.00	-4.39
Not profound	-2.97	0.00	0.00	Profound SNHL	1	-2.97	Profound SNHL	1.00	-2.97
10 years	0.33	10.00	3.31	10.00	10	3.31	10 years	10.00	3.31
Intercept			7.65			7.65			7.65
Predicted			10.96			7.99			3.60
95.0%CL			8.59			6.88			1.31
+95.0%CL			13.34			9.11			5.89

Note that *B-weight* is the coefficient attached to the variable under consideration. *Value* refers to the value attached to the particular child. In the case of a dummy variable, this value would be 0 if the child does not have the characteristic and 1 if he or she does.

As regression analysis identified SNHL and poor dynamic visual acuity as significant predictors of motor function, this indicates that motor performance is dependent on more than just the function of the SCC. This might present a need for routine evaluation of the motor function of children with profound hearing loss to ensure that appropriate intervention is given in the case of poor motor performance.

With increased age, central vestibular compensation is acquired due to the plasticity of the immature brain (Kaga, 1999). Visual and somatosensory systems compensate for the loss of vestibular function, and children with VH reach their motor developmental milestones by adolescence (Kaga 1999; Kaga et al., 2008). This might be the reason why participants with SNHL in the current study scored better on the M-ABC-2 with increased age.

The only two variables retained by the forward stepwise model in predicting performance on the M-ABC-2, in the group with SNHL and in the normal-hearing

group, were the presence of an increased DVA score and the presence of SNHL. As mentioned before, an increased DVA score is an indication of VH and more likely BVH (Rine & Braswell, 2003). This may be a confirmation that the DVA test is a reliable clinical test in predicting motor performance.

5.4 Summary of the discussion

According to the results of the study, reduced intensity and duration of nystagmus (as induced by the modified SCPNT) and poor dynamic visual acuity (as determined by the DVA test) are associated with SNHL. The current study also showed that reduced intensity and duration of nystagmus are associated with poor dynamic visual acuity in children with SNHL.

It was also found that there is a significant difference in the scores on the M-ABC-2 between:

- children with SNHL and children with normal hearing matched according to age and gender;
- children with poor dynamic visual acuity and children with normal dynamic visual acuity in the SNHL group.

No significant difference was found in the scores of the M-ABC-2 between children with reduced intensity and duration of nystagmus and children with normal intensity and duration of nystagmus in the group with SNHL.

As results of the study indicated that motor performance can be predicted by dynamic visual acuity and the degree of SNHL the null hypothesis is rejected.

6 CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the possible limitations and recommendations of the study are discussed. This is followed by the conclusions drawn from the interpretation of the empirical results of the study.

6.1 Limitations of the research

Limitations with regard to the literature review and empirical study are discussed in the following sections.

6.1.1 Limitations with regard to the literature review

Limited published studies are available that reported about the dynamic visual acuity of children with SNHL. Only one study (Braswell & Rine, 2006a) could be found that used the DVA test as a measure for dynamic visual acuity. An extensive literature review on the dynamic visual acuity of children with SNHL was therefore not possible.

6.1.2 Limitations with regard to the empirical study

These limitations refer to the gathering of data. The quality of data gathering is dependent on the abilities of the researcher as well as the willingness and the ability of the participants to co-operate and to concentrate.

The accuracy of the SCPNT was dependent on the researcher's ability to observe nystagmus. The SCPNT does not measure the speed of the slow component of the nystagmus as with an ENG but rather the duration of nystagmus and the number of beats as counted by the researcher. The number of beats in a ten-second period was counted to get an indication of the speed of the nystagmus. This adjustment to the SCPNT seems to be a more accurate measure of vestibular function than the classic SCPNT. However, these are subjective measures and there is a possibility that the investigator could have missed some of the beats of nystagmus because the direction of gaze could have influenced the strength of the nystagmus (Tusa, 2007). Although the chair rotation was done to the beat of a metronome, it is possible that the speed of the rotation of the chair could have been inconsistent. It is also possible that the SCPNT does not identify VH. To determine whether the SCPNT measures vestibular function, it needs to be correlated with caloric and rotary chair testing. This was however beyond the scope of the current study.

It is possible that the time of day that participants were evaluated could have had an effect on the accuracy of the tests, especially the DVA test. This might particularly have been the case with pre-school participants who had difficulty in concentrating after a busy school day. It might also have been important to limit the physical activities of participants prior to the test procedures to ensure optimal concentration.

Although it is unlikely for participants with congenital or early acquired vestibular deficits to experience oscillopsia (Longridge & Mallinson, 1987), a visual analogue scale to determine the presence of oscillopsia could have been added to the instruments used in the current study. A visual analogue scale could indicate whether the children are aware of the presence of poor dynamic visual acuity.

The selection of participants was done by audiologists who knew the children and their histories at the different schools. It is possible that some of the participants might have had other conditions that had not been diagnosed and of which the audiologists were unaware. The health questionnaire that had to be completed by the parents was used to address this possibility.

Randomised sampling was not used to select participants but rather convenience sampling for the first phase, and purposive sampling for the second phase of the study. The findings of this research can therefore not be generalised to the population with SNHL. There is also the possibility of sampling bias, whether consciously or unconsciously, because of the method of sampling.

The majority of participants in the second phase of the study had congenital SNHL. This was unintentional, but the aetiology of the hearing loss might have had an influence on vestibular function.

6.2 Recommendations

The results of the study indicate that there might be a need to test the DVA of children with SNHL to determine whether there is a problem with the dynamic visual acuity of these children. Poor dynamic visual acuity may lead to problems with reading and learning difficulties.

It is recommended that, when the DVA test is used for young children, such children should be tested when they are not tired, as tiredness may have an influence on the re-test reliability of the test. Physical activity should also be limited prior to the test procedure because of the possibility of overtiredness.

Because VH and poor dynamic visual acuity may have an enormous impact on the quality of life of children with SNHL (Braswell & Rine, 2006a), it is important that service providers who often work with such children need adequate knowledge to identify dysfunction of the vestibular system. It is therefore recommended that assessment of the vestibular system and treatment of vestibular dysfunction are included in the undergraduate curriculum of physiotherapy, audiology and occupational therapy students.

Parents and caregivers should be informed about the potential safety risks that children with a DVA abnormality and VH are exposed to.

As the majority of participants in the current study had congenital SNHL, further research is needed that will include more participants with acquired SNHL. The aetiology of SNHL might have an influence on the prevalence of VH in children with SNHL.

Further research is needed to determine whether vestibular rehabilitation exercises, particularly gaze stability exercises, will improve the dynamic visual acuity and motor performance in children with SNHL. Gaze stability exercise could be included in parent guidance sessions. Parents can be taught to do these exercises with their children as a home programme. This might be a feasible way to provide therapy to children with gaze instability, especially in developing countries with limited resources and service providers.

The results of the study with regard to the motor proficiency of children with SNHL, especially children with profound SNHL, raise the question as to whether these children need screening motor tests to determine whether they need vestibular and balance rehabilitation therapy.

Because no published South African studies could be found regarding the vestibular function of children with SNHL, more research is needed in this field in South Africa and other developing countries.

6.3 Conclusions

The results of this study indicated that an increased DVA score and poor dynamic visual acuity are associated with SNHL in some subjects. It is important to evaluate children with SNHL for the presence of a DVA abnormality as the latter can have serious implications for the safety, education and general well being of these

children. Children with DVA abnormalities should be referred for appropriate therapy. Gaze stability exercises might be beneficial for children with poor dynamic visual acuity.

Children with profound SNHL should be screened routinely for motor deficits because such children are at risk of having problems with motor performance, especially with balance. Problems with motor proficiency should be addressed by means of appropriate intervention to ensure optimal quality of life.

Reduced duration and intensity of nystagmus induced by the SCPNT is not an accurate measure of vestibular function. It is therefore recommended that the SCPNT be not to be used as an assessment tool to determine vestibular function.

Recommendations should be made to parents and caregivers regarding safety during normal childhood activities, including swimming, riding bicycles and crossing roads.

REFERENCES

- Aneja, S., & Aggarwal, A. (1997). Acute bacterial meningitis. *Indian Pediatrics*, 34, 1097–1107.
- Angeli, S. (2003). Value of vestibular testing in young children with sensorineural hearing loss. *Archives of Otolaryngology – Head and Neck Surgery*, 129, 478–482.
- Arnvig, J. (1955). Vestibular function in deafness and severe hardness of hearing. *Acta Oto-Laryngologica*, 45, 283–288.
- Ayres, A.J. (1989). Southern California Postrotary Nystagmus Test. Los Angeles, California: Western Psychological Services.
- Bakr, M.S., Ezzat, M., & Saleh, M.D. (2000). Electronystagmography: How helpful is it? *Journal of Laryngology and Otology*, 114, 178–183.
- Barber, H., & Stockwell, C. (1980). Manual of electronystagmography. (2nd ed.). Missouri: The CV Mosby Company.
- Beynon, G.J., Jani, P., & Baguley, D.M. (1998). A clinical evaluation of head impulse testing. *Clinical Otolaryngology*, 23, 117–122.
- Braswell, J., & Rine, R.M. (2006a). Evidence that vestibular hypofunction affects reading acuity in children. *International Journal of Pediatric Otorhinolaryngology*, 70, 1957–1965.
- Braswell, J., & Rine, R.M. (2006b). Preliminary evidence of improved gaze stability following exercise in two children with vestibular hypofunction. *International Journal of Pediatric Otorhinolaryngology*, 70, 1967–1973.
- Casselbrandt, M.L., & Mandel, E.M. (2005). Balance disorders in children. *Neurologic Clinics*, 23, 807–829.
- Casselbrandt, M.L., Vilardo, R.M.J., & Mandel, E.M. (2008). Balance and otitis media with effusion. *International Journal of Audiology*, 47, 584–589.

- Chow, S., & Henderson, S.E. (2003). Inter-rater and test-retest reliability of the Movement Assessment Battery for Chinese pre-school children. *The American Journal of Occupational Therapy*, 57, 574–577.
- Cintas, H.L., Siegel, K. L., Furst, G. P., & Gerber, L.H. (2003). Brief assessment of motor function: Reliability and concurrent validity of the Gross Motor Scale. *American Journal of Physical Medicine*, 82, 33–41.
- Crowe, T.K., & Horak, F.B. (1988). Motor proficiency associated with vestibular deficits in children with hearing impairments. *Physical Therapy*, 68, 1493–1499.
- Curthoys, I.S., & Halmagyi, G.M. (2007). Vestibular compensation: Clinical changes in vestibular function with time after unilateral vestibular loss. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 76–97). Philadelphia: FA Davis.
- Cushing, S.L., Papsin, B.C., Rutka, J.A., James, A.L., & Gorden, K.A. (2008). Evidence of vestibular and balance dysfunction in children with profound sensorineural hearing loss using cochlear implants. *The Laryngoscope*, 118, 1814–1823.
- Cyr, D.V., Brookhouser, P.E., Valente, M., & Grossman, A. (1985). Vestibular evaluation of infants and preschool children. *Archives of Otolaryngology – Head and Neck Surgery*, 93, 463–468.
- Dannenbaum, E., Paquet, N., Hakim-Zadeh, R., & Feldman, A.G. (2005). Optimal parameters for the clinical test of dynamic visual acuity in patients with unilateral vestibular deficit. *The Journal of Otolaryngology*, 34, 13–19.
- Deitz, J.C., Crowe, T.K., & Siegner, C.B. (1981). The Southern California Postrotary Nystagmus test, test-re-test reliability for pre-school children. *The Occupational Therapy Journal of Research*, 1, 165–171.
- Diamond, A. (2000). Close interrelationship of motor development and cognitive development and of the cerebellum and prefrontal cortex. *Child Development*, 71, 44–56.

- Durrheim, K. (2006). Research design. In M. Terre Blanche, K. Durrheim & D. Painter (Eds.), *Research in practice* (2nd ed., pp. 34–59). Lansdowne: UCT Press.
- Fetter, M. (2007). Vestibular system disorders. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 98–106). Philadelphia: FA Davis.
- Fife, T.D., Tusa, R.J., Furman, J.M., Zee, D.S., Frohman, E., Baloh, R.W., et al. (2000). Assessment: Vestibular testing techniques in adults and children. *Neurology*, 55, 1431–1441.
- Filipo, R., Patrizi, M., La Gamma, R., D'Elia, C., La Rosa, G., & Barbara, M. (2006). Vestibular impairment and cochlear implantation. *Acta Otolaryngologica*, 126, 1266–1274.
- Foster, C.A., Foster, B.D., Spindler, J., & Harris J.P. (1994). Functional loss of the horizontal doll's eye reflex following unilateral vestibular lesions. *The Laryngoscope*, 104, 473–478.
- Fuller, K. (1996). Understanding the unilateral peripheral vestibular lesion. *Journal of Neurologic Physical Therapy*, 20, 7–9.
- Gayle, G., & Pohlman, R.L. (1991). Comparative study of the dynamic, static and rotary balance of deaf and hearing children. *Perceptual and Motor Skills*, 73, 882–887.
- Green, S.B. & Salkind N.J. (2008). Using SPSS for Windows and Macintosh. Analyzing and understanding data. (5th ed.). New Jersey: Pearson Education.
- Grossman, G.E., & Leigh, R.J. (1990). Instability of gaze during locomotion in patients with deficient vestibular function. *Annals of Neurology*, 27, 528–532.
- Hain, T.C., & Helminski, J.O. (2007). Anatomy and physiology of the normal vestibular system. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 2–18). Philadelphia: FA Davis.

- Halmagyi, G.M., & Curthoys, I.S. (1988). A clinical sign of canal paresis. *Archives of Neurology*, 45, 737–739.
- Halmagyi, G.M., & Curthoys, I.S. (2007). Otolith function tests. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 144–161). Philadelphia: FA Davis.
- Harvey, S.A., & Wood, D.J. (1996). The oculoccephalic response in the evaluation of the dizzy patient. *The Laryngoscope*, 106, 6–9.
- Harvey, S.A., Wood, D.J., & Feroah, T.A. (1997). Relationship of the head impulse test and head-shake nystagmus in reference to caloric testing. *American Journal of Otology*, 18, 207–213.
- Hattie, J., & Edwards, H. (1987). A review of the Bruininks-Oseretsky test of motor proficiency. *British Journal of Educational Psychology*, 57, 104–113.
- Hayley, S.M., Coster, W.J., Ludlow, L.H., Haltwanger, J.T., & Andrello, P.J. (1994). The Pediatric Evaluation of Disability Inventory. *Pediatric Physical Therapy*, 6, 42–50.
- Henderson, S.E., Sugden, D.A., & Barnett, A.L. (2007). Movement Assessment Battery for Children-2. (2nd ed.). London: Harcourt Assessment.
- Herdman, S.J., & Clendaniel, R.A. (2007). Assessment and treatment of complete vestibular loss. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 338–359). Philadelphia: FA Davis.
- Herdman, S.J., Hall, C.D., Schubert, M.C., Das, V.E., & Tusa, R.J. (2007). Recovery of dynamic visual acuity in bilateral vestibular hypofunction. *Archives of Otolaryngology – Head and Neck Surgery*, 133, 383–389.
- Herdman, S.J., & Whitney, S.L. (2007). Interventions for patients with vestibular hypofunction. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 309–337). Philadelphia: FA Davis.

- Honrubia, V. (2000). Quantitative vestibular tests and clinical examination. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (2nd ed., pp. 105–171). Philadelphia: FA Davis.
- Horak, F.B. (2007). Role of the vestibular system in postural control. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 32–53). Philadelphia: FA Davis.
- Horak, F.B., Shumway-Cook, A., Crowe, T.K., & Black, F.O. (1987). Vestibular function and motor proficiency of children with impaired hearing, or with learning disability and motor impairments. *Developmental Medicine and Child Neurology*, 30, 64–79.
- Johnson, C.E. & Danhauer, J. L. (2002). *Handbook of outcomes measures in audiology*. Clifton Park, U. S. A.: Delmar Cengage Learning.
- Johnson, M.H., Hasenstab, M.S., Seicshnaydre, M.A., & Williams, G.H. (1995). CT of postmeningitis deafness: Observations and predictive value for cochlear implants in children. *American Journal of Radiology*, 16, 103–109.
- Junaid, A.K., & Fellowes, S. (2006). Gender differences in the attainment of motor skills on the Movement Assessment Battery for Children. *Physical and Occupational Therapy in Paediatrics*, 26, 5–11.
- Kaga, K. (1999). Vestibular compensation in infants and children with congenital and acquired vestibular loss in both ears. *International Journal of Pediatric Otorhinolaryngology*, 49, 215–224.
- Kaga, K., Shinjo, Y., Jin, Y., & Takegoshi, H. (2008). Vestibular failure in children with congenital deafness. *International Journal of Audiology*, 47, 590–599.
- Kanjee, A. (2006). Assessment research. In M. Terre Blanche, K. Durrheim & D. Painter (Eds.), *Research in practice* (2nd ed., pp. 470–498). Lansdowne: UCT Press.

- Keating, K.S. (1979). A comparison of nystagmus as measured by the Southern California Postrotary Nystagmus Test and electronystagmography. *American Journal of Occupational Therapy*, 33, 92–97.
- Kennedy, K.S. (1981). The Southern California Postrotary Nystagmus Test: Los Angeles versus Syracuse data. *The Occupational Therapy Journal of Research*, 32, 93–103.
- Kimball, J.G. (1981). Normative comparison of the Southern California Postrotary Nystagmus Test: Los Angeles vs. Syracuse data. *The American Journal of Occupational Therapy*, 35, 21–25.
- Lachenicht, L. (2002a). Distribution-free tests. In C. Tredoux & K. Durrheim (Eds.), *Numbers, hypothesis & conclusions: A course in statistics for the social sciences* (pp. 385-401). Lansdowne: UCT Press .
- Lachenicht, L. (2002b). Probability and theoretical distribution. In C. Tredoux & K. Durrheim (Eds.), *Numbers, hypothesis & conclusions: A course in statistics for the social sciences* (pp. 70–89). Lansdowne: UCT Press .
- Lee, C. (1999). Eye and head coordination in reading: Roles of head movement and cognitive control. *Vision Research*, 39, 3761–3768.
- Leigh, R.J. (2007). Pharmacological and optical methods of treating vestibular disorders and nystagmus. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 178–187). Philadelphia: FA Davis.
- Levy, D.L., Proctor, L.R., & Holzman, P.S. (1977). Visual interference on vestibular response. *Archives of Otorhinolaryngology*, 103, 287–291.
- Longridge, N.S., & Mallison, A.I. (1987). The dynamic illegible E-test. *Acta Otolaryngologica*, 103, 273–279.
- MacCobb, S., Greene, S., Nugent, K., & O'Mahony, P. (2005). Measurement and prediction of motor proficiency in children using Bayley Infant Scales and the

- Bruininks-Oseretsky test. *Physical & Occupational Therapy in Pediatrics*, 25, 59–79.
- Magnussen, L., Ehiri, J., & Jolly, P. (2004). Comprehensive versus selective primary health care; lessons for global health policy. *Health Affairs*, 23, 167-176.
- McGraw, K.O., & Wong, S.P. (1996). Forming inferences about some intraclass correlation coefficients. *Psychological Methods*, 1, 30–46.
- Medical Research Council. (2004). *MRC Ethics Guide: Medical research involving children*. MRC. Retrieved April 22, 2008, from <http://www.mrc.co.za>
- Mehta, Z., & Stakiw, D.B. (2004). Childhood vestibular disorders: A tutorial. *Communication Disorders Quarterly*, 26, 5–16.
- Morrison, D., & Sublett, J. (1983). Reliability of the Southern California Postrotary Nystagmus Test with learning-disabled children. *The American Journal of Occupational Therapy*, 37, 694–698.
- Nadol, J.B., & Hsu, W. (1991). Histopathologic correlation of spiral ganglion cell count and new bone formation in the cochlea following meningogenic labyrinthitis and deafness. *Annals of Otology, Rhinology and Laryngology*, 37, 712–716.
- Nandi, R., & Luxon, L.M. (2008). Development and assessment of the vestibular system. *International Journal of Audiology*, 47, 566–577.
- Nelson, D.L., Weidensaul, N.K., Anderson, V.G., & Shih, L.S. (1984). The Southern California Postrotary Nystagmus Test and electronystagmography under different conditions of visual input. *The American Journal of Occupational Therapy*, 38, 535–540.
- Northern, J.L., & Downs, M.P. (2001). *Hearing in children*. (3rd ed.). Baltimore: Williams & Wilkins.

- Parush, S., Winokur, M., Goldstand, S., & Miller, L.J. (2002). Prediction of school performance using the Miller Assessment for Preschoolers (MAP): A validity study. *American Journal of Occupational Therapy*, 56, 547–555.
- Polatajko, H.J. (1985). A critical look at vestibular dysfunction in learning disabled children. *Developmental Medicine & Child Neurology*, 27, 283–292.
- Rine, R.M. (2007). Management of the pediatric patient with vestibular hypofunction. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 360–375). Philadelphia: FA Davis.
- Rine, R.M., & Braswell, J. (2003). A clinical test of dynamic visual acuity for children. *International Journal of Pediatric Otorhinolaryngology*, 67, 1195–1201.
- Rine, R.M., Braswell, J., Fisher, D., Joyce, K., Kalar, K., & Shaffer, M. (2004). Improvement of motor development and postural control following intervention in children with sensorineural hearing loss and vestibular impairment. *International Journal of Pediatric Otorhinolaryngology*, 68, 1141–1148.
- Rine, R.M., Cornwall G., Gan, K., LoCascio, C., O'Hare, T., Robinson, E., et al. (2000). Evidence of progressive delay of motor development in children with sensorineural hearing loss and concurrent vestibular dysfunction. *Perceptual and Motor Skills*, 90, 1101–1112.
- Rine, R.M., Linbald, S., Donovan, P., Vergara, K.G., & Mattson, K. (1996). Balance and motor skills in young children with sensorineural hearing impairment: A preliminary study. *Pediatric Physical Therapy*, 8, 55–61.
- Roos, K.L. (1999). Encephalitis. *Neurologic Clinics*, 17, 813–833.
- Rösblad, B., & Gard, L. (1998). The assessment of children with developmental coordination disorders in Sweden: A preliminary investigation of the suitability of the Movement ABC. *Human Movement Science*, 17, 711–719.

- Rosenbult, B., Goldstein, R., & Landau, W.M. (1960). Vestibular responses of some deaf and aphasic children. *The Annals of Otology, Rhinology, and Laryngology*, 69, 747–755.
- Royeen, C.B. (1980). Factors affecting test-retest reliability of the Southern California Postrotary Nystagmus Test. *The American Journal of Occupational Therapy*, 34, 37–39.
- Santaella, R.M., & Fraunfelder, F.W. (2007). Ocular adverse effects associated with systemic medications: Recognition and management. *Drugs*, 67, 75–93.
- Schubert, M.C. (2007). Compensatory strategies for vestibulo-ocular hypofunction. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 265–271.). Philadelphia: FA Davis.
- Schubert, M.C., & Minor, L.B. (2004). Vestibulo-ocular physiology underlying vestibular hypofunction. *Physical Therapy*, 84, 373–385.
- Schubert, M.C., & Shepard, T.N. (2008). Practical anatomy and physiology of the vestibular system. In T.N. Shepard & G.P. Jacobson (Eds.), *Balance function assessment and management* (2nd ed., pp. 2–18). San Diego: Plural Publishing.
- Schubert, M.C., Tusa, R.J., Grine, L.E., & Herdman, S.J. (2004). Optimizing the sensitivity of the head thrust test for identifying vestibular hypofunction. *Physical Therapy*, 84, 151–158.
- Selz, P.A., Girardi, M., Konrad, H.R., & Hughes, L.F. (1996). Vestibular deficits in deaf children. *Archives of Otolaryngology – Head and Neck Surgery*, 115, 70–77.
- Shepard, T.N., & Janky, K.L., (2008). Background and technique of computerised dynamic posturography. In T.N. Shepard & G.P. Jacobson (Eds.), *Balance function assessment and management* (2nd ed., pp. 359–378). San Diego: Plural Publishing.

- Shimizu, R., Yoneda, T., Minagawa, H., Ohnishi, N., & Uchiyama, M. (1999). A system for helping blind children acquire spatial awareness. *Technology & Disability*, 11, 143–149.
- Smith, R.J., Bale, J.F., & White, K. (2005). Sensorineural hearing loss in children. *The Lancet*, 365, 879–890.
- Smits-Engelsman, B.C., Henderson, S.E., & Michels, C.G. (1998). The assessment of children with developmental coordination disorders in the Netherlands: The relationship between the Movement Assessment Battery for Children and the Körperkoordinationstest für Kinder. *Human Movement Science*, 17, 699–709.
- Swanepoel, D.W., Störbeck, C., & Friedland, P. (2009). Early hearing detection and intervention in South Africa. *International Journal of Pediatric Otorhinolaryngology*, 73, 783–786.
- Takahashi, S., Fetter, M., Koenig, E., & Dichgans, J. (1990). The clinical significance of head-shaking nystagmus in the dizzy patient. *Acta Otolaryngologica*, 109, 8–14.
- Tee, L.H., & Chee, N.W. (2005). Vestibular rehabilitation therapy for the dizzy patient. *Annals of the Academy of Medicine, Singapore*, 34, 289–294.
- Telisch, F.F., Rodgers, G.K., & Balkany, T.J. (2000). Dizziness in childhood. In R.K. Jackler & D.E. Brackman (Eds.), *Neurotology* (2nd ed., pp. 553–585). Philadelphia, Elsevier Mosby.
- Tribukait, A., Brantberg, K., & Bergenhuys, J. (2004). Function of semicircular canals. Utricles and saccules in deaf children. *Acta Otolaryngologica*, 124, 41–48.
- Tsuzuku, T., & Kaga, K. (1992). Delayed motor function and results of vestibular function tests in children with inner ear anomalies. *International Journal of Pediatric Otorhinolaryngology*, 23, 261–268.

- Tusa, R. (2005). Bedside assessment of the dizzy patient. *Neurologic Clinics*, 23, 655–673.
- Tusa, R. (2007). History and clinical examination. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 108–124). Philadelphia: FA Davis.
- Van Hartingsveldt, M.J., Cup, E.H., & Oostendorp, R.A. (2005). Reliability and validity of the fine motor scale of the Peabody Developmental Motor Scales-2. *Occupational Therapy International*, 12, 1–13.
- Van Waelvelde, H., De Weerd, W., De Cock, P., & Smits-Engelsman, B.C. (2004). Aspects of the validity of the Movement Assessment Battery for Children. *Human Movement Science*, 23, 49–60.
- Waldron, M.N., Matthews, J.N., & Johnson, I.J. (2004). The effect of otitis media with effusions on balance in children. *Clinical Otolaryngology*, 29, 318–320.
- Wassenaar, D.R. (2006). Ethical issues in social science research. In M. Terre Blanche & K. Durrheim (Eds.), *Research in practice* (2nd ed., pp. 67–68). Lansdowne: UCT Press.
- Wei, D., Hain, T.C., & Proctor, L.R. (1989). Head shaking nystagmus: Associations with canal paresis and hearing loss. *Acta Otolaryngologica*, 108, 362–367.
- Whitney S.L., & Herdman, S.J. (2007). Physical therapy assessment of vestibular hypofunction. In S.J. Herdman (Ed.), *Vestibular rehabilitation* (3rd ed., pp. 272–329). Philadelphia: FA Davis.
- Wiener-Vacher, S.R. (2008). Vestibular disorders in children. *International Journal of Audiology*, 47, 578–583.
- Woollacott, M.H., & Shumway-Cook, A. (1990). Changes in posture control across life span: A systems approach. *Physical Therapy*, 70, 799–807.
- Wuyts, F.L., Furman, J., Vanspauwen, R., & Van de Heyning, P. (2007). Vestibular function testing. *Current Opinion in Neurology*, 20, 19–24.

Appendix A

Laboratory measures of vestibular function

The VOR is typically measured during vestibular stimulation to assess the function of the vestibular system (Schubert & Minor, 2004). The VOR phase represents the timing relationship for the eye and head position. Eye position should arrive at a point in time that is equal to the oppositely directed head position. This is described as zero phase shift (Schubert & Minor, 2004).

- **Electronystagmography**

Eye movements can be recorded by means of electronystagmography (ENG) (Fife, et al., 2000). It provides a permanent record of eye movements. This can be achieved with eyes closed or open and also in complete darkness. During the ENG, the eye acts like a battery. The cornea is the positive pole and the retina, the negative pole. The potential difference between the cornea and retina is normally 1 mv. Electrodes are placed around the eye to monitor eye movements. This permits recordings of the direction, amplitude, and velocity of eye movements (Barber & Stockwell, 1980; Fife et al., 2000). ENG is used to monitor eye movements during a battery of vestibular and oculomotor tests. A disadvantage of an ENG is that it cannot detect torsional movement, only vertical and horizontal movement with the result that test results may be misinterpreted in nystagmus, which has a torsional component. ENG is only useful when it is done by a skilled interpreter with knowledge of the physiology and pathophysiology of the vestibular system (Bakr, Ezzat & Saleh, 2000). It can also be challenging to perform an ENG on a child. A great deal of skill and patience is needed to get children to cooperate to perform an ENG accurately. Children might be frightened by the dark and they may feel intimidated by the equipment. A detailed history and physical examination of the patient is often enough to make a diagnosis, especially when a peripheral vestibular lesion is suspected. In these cases, the ENG adds no more information than the detailed history and physical examination (Bakr et al., 2000). However, the ENG is useful to distinguish central vestibular lesions from peripheral vestibular impairment (Bakr et al., 2000). Infrared video nystagmography (VNG) is another way to record eye movements. Infrared cameras are used to detect eye movements in darkness. Torsional and horizontal eye movements are easy to record, but vertical eye movements are more difficult to record due to eyelid movement artefacts (Fife et al.,

2000). Both ENG and VNG recordings are very expensive and not readily available in South Africa; they were therefore not suitable for the current study.

- Caloric testing

Caloric irrigation is a quantitative test where the peripheral vestibular system is stimulated (Schubert & Minor, 2004). Each ear is irrigated with water/air heated or cooled to above or below body temperature. The irrigation stimulates the horizontal SCC of the irrigated ear and usually results in a horizontal nystagmus. With the caloric test, the sensitivity of the left peripheral vestibular system is compared with the sensitivity of the right peripheral vestibular system. However, only the horizontal SCC can be evaluated. The anterior and posterior SCC are not stimulated by caloric irrigation due to the anatomy of the ear (Barber & Stockwell, 1980). Thus, abnormal results with caloric testing do not imply that the labyrinth is totally dysfunctional; so they should be used together with other tests like rotational testing ((Wuyts, Furman, Vanspauwen & Van de Heyning, 2007).

The caloric test has however been described as the gold standard for identifying UVH. The caloric test was the most accurate test for the purpose of the current study. However, physical features of the external ear canal or temporal bone and variations in blood flow can affect the accuracy of the test. Caloric irrigation is also not tolerated very well by young children because it is unpleasant (Barber & Stockwell, 1980; Cyr, Brookhouser, Valente & Grossman,). It is difficult to get pre-school children to cooperate, especially if taken into consideration that bithermal irrigations are needed (Cyr et al., 1985).

- Rotational chair testing

A test not often performed in South Africa is the rotary chair test. The equipment to perform this test is not widely available in South Africa due to the associated costs. It provides a physiological stimulation of both horizontal SCC. It is done in combination with ENG. The patient is seated on a rotary chair. The chair is under computer control and mounted on a motorised rotating platform. Testing is done in a dark, acoustically treated room. Electro-oculographic calibrations are frequently done throughout the testing procedure. The neck is flexed 30° and fixated in that position to obtain maximal horizontal SCC stimulation. Whole body-earth vertical rotation is performed at a range of frequencies from about 0.01 Hz to 1.0 Hz. The patient is kept alert by frequently asking questions to which he/she must respond. Measures

usually obtained include gain, phase and asymmetry. The rotary chair test is the gold standard for bilateral vestibular hypofunction (Schubert & Minor, 2004). The advantage of this test is that it is a physiological stimulus, it is well tolerated by children and a young child can be seated on the mother's lap while the test is performed (Schubert & Minor, 2004). Another advantage is that anatomical variations of the middle ear and temporal bone do not influence the accuracy of the test (Fife et al., 2000). Disadvantages of the rotational test are that rotation affects both labyrinths simultaneously, it is less accurate in detecting unilateral lesions, and fatigue or inattentiveness can suppress the VOR. Therefore, mental alerting tasks must be used to increase accuracy (Fife et al., 2000). It may be difficult to get children to cooperate to perform mental alerting tasks.

Appendix B

Assessment tools of motor system function

The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) tests motor functioning of children from four and a half to fourteen and a half years of age (MacCobb, Greene, Nugent & O'Mahony, 2005). The complete battery comprises 46 separate items which contribute to the following subtests: running speed and agility, static and dynamic balance, bilateral coordination of upper and lower limbs, strength, upper limb coordination and visual tracking, response speed to a moving visual stimulus, visual motor control, upper limb speed and dexterity (MacCobb et al., 2005). However, there is some evidence that the BOTMP lacks a sound psychometric foundation for the aggregation of the subtest scores to produce a single battery composite score (Hattie & Edwards, 1987).

The Peabody Developmental Motor Scales-2 (PDMS-2) was designed to evaluate both fine and gross motor skills in children from birth to 72 months (Van Hartingsveldt, Cup & Oostendorp, 2005). It consists of six subtests: reflexes (birth to 11 months), stationary balance, locomotion, object manipulation, grasping and visual-motor integration. Due to the age group at which the tests are aimed, i.e. from birth to 72 months, and the age group of the participants in this study, i.e. between 4 and 14 years of age, the PDMS-2 was not suitable for this study.

The Brief Assessment of Motor Function (BAMF) is a series of 10-point ordinal scales developed for rapid description of gross motor, fine motor, and oral motor performance (Cintas, Siegel, Furst & Gerber, 2003). It was specifically designed for the evaluation of infants and children with disabilities. This test is suitable for children displaying a wide range of perambulatory and ambulatory ability. It is however not a comprehensive assessment of multiple motor skills. The results of the BAMF indicate the child's ability in relation to the highest bi-pedal skill (Cintas et al., 2003). The study population was not expected to show any outward signs of motor incompetency. The children taking part in this study could all sit, walk without support and run. For this reason, this test was not suitable for the current study.

The Pediatric Evaluation of Disability Inventory (PEDI) assesses the functional ability of children with significant neuromotor dysfunction (Hayley, Coster, Ludlow, Haltwanger & Andrello 1992). The study population was not expected to have

significant neuromotor dysfunction. However, the study population might have had mild gross motor dysfunction and problems with balance activities.

The Miller Assessment for Preschoolers (MAP) evaluates the sensory, motor, perceptual, cognitive and verbal performance of preschool children in an appealing game format (Parush, Winokur, Goldstand & Miller, 2002). This test was however not suitable for this study because it is only appropriate for preschool children and the current study included children between four and fourteen years of age.

Appendix C

Description of test items of the M-ABC

Age band 1: To test manual dexterity the child is asked to post coins into a bank box. In the case of children three to four years of age, six coins had to be posted, first with the preferred hand and then with the other hand. In the case of children between five and six years of age, twelve coins had to be posted. The time to complete the task was taken in seconds. The child was then asked to thread beads as quickly as possible in a lace. This was done by using the preferred hand. Time to complete the task was taken in seconds. The next task was to trace with a pen between two curved lines without crossing the lines. The number of errors was documented. Ball skills were tested by asking the child to catch a bean bag. The examiner stands 1.8 meters from the child. Children aged three to four years old were allowed to trap the bean bag against the body. Five- to six-year-olds had to catch the bean bag without trapping it against the body. The number of catches out of 10 attempts executed correctly was documented. For the next task, the child was asked to throw a bean bag to a target mat 1.8 meters away. The number of successful hits out of 10 attempts was documented. To evaluate static balance, the child was asked to stand on one leg as long as possible for up to 30 seconds. This was done with the preferred leg and then repeated with the other leg. For dynamic balance, the child was asked to walk on the toes on a line for 15 steps or 4.5 meters, whichever came first. The number of steps was documented. Then the child was asked to jump from a stationary position with feet together for five consecutive jumps. After the fifth jump, the child had to maintain balance, otherwise the last jump did not count. The number of successful jumps was documented.

Age band 2: To test manual dexterity, the child was asked to perform the following tasks: the child needed to place 12 pegs in the holes of a board, first with the preferred hand and then with the other hand. Then the child was asked to thread lace through the holes in the board. The time to complete the separate tasks was taken in seconds. The next task was to trace with a pen between two curved lines without crossing the lines. The number of errors was documented. To test ball skills, the child was asked to bounce a tennis ball against the wall and to catch it with both hands. The number of catches was counted. Then the child was instructed to throw a bean bag onto a circle on a mat with the preferred hand from a distance of 1.8

meters. The number of hits was documented. To evaluate static balance, the child was asked to stand on a balance board on one foot long as possible or up to 30 seconds. The test was done first on the preferred leg and then repeated on the other leg. The time the child was able to maintain his/her balance was documented. To test dynamic balance, the child was asked to make five continuous jumps on one leg from square mat to square mat placed on the floor. The preferred leg was tested first, followed by the other leg. The number of jumps was counted. The next task was to walk along a 4,5-meter line, placing the heel of one foot against the toes of the other foot. The number of steps that the child was able to do without losing his/her balance was documented.

Age band 3: To test manual dexterity the child was presented with a peg board with pegs that were red at the one end and yellow at the other end. The pegs were inserted into the holes of the peg board with one colour consistently showing. The child was then asked to invert the pegs first and to replace them into the holes as quickly as possible with the preferred hand. The time to complete the task was documented. It was then repeated with the other hand. Next, the child was asked to construct a triangle with three plastic strips, three bolts and three nuts. The time to complete the task was documented. The next task was to trace with a pen between two curved lines without crossing the lines. The number of errors was documented. To test ball skills, the child was asked to throw a tennis ball first with the preferred hand against the wall from a distance of 2 m. The child had to catch the ball again with the preferred hand without it bouncing on the floor. The number of successful catches out of 10 attempts was documented. It was then repeated with the other hand. The next task was to throw a tennis ball at a target against the wall from a distance of 2.5 meters. The number of successful hits out of 10 throws was documented. This was done only with the preferred hand. For static balance, the child had to stand heel-to-toe on a narrow balance board for up to 30 seconds. The number of seconds the child was able to maintain balance was documented. For dynamic balance, the child had to walk backwards on a line placing the toe of the one foot against the heel of the other foot with each step. The number of steps up to 15 steps or 4.5 meters, whichever came first, was documented. For dynamic balance, the child was asked to hop on coloured mats placed in a zig-zag line. The child had to make five consecutive hops from one mat to the next and had to

maintain balance on the last mat. The number of successful hops was documented. Both legs were tested (Henderson, Sugden & Barnett, 2007).

Appendix D

Questionnaire regarding your child's health (hearing loss)

Name of child: _____ Date of birth: _____

Phone number: _____ Age: _____

Please tick the appropriate answer:

Has your child ever had a head injury?	Yes	No
----------------------------------------	-----	----

Did your child have meningitis?	Yes	No
---------------------------------	-----	----

Did your child have encephalitis?	Yes	No
-----------------------------------	-----	----

Has your child ever had a fit?	Yes	No
--------------------------------	-----	----

Does your child have any visual problems?	Yes	No
-------------------------------------------	-----	----

Does your child have any hearing problems?	Yes	No
--------------------------------------------	-----	----

Were learning difficulties identified by your child's teacher?	Yes	No
----------------------------------------------------------------	-----	----

Has your child been diagnosed with cerebral palsy?	Yes	No
----------------------------------------------------	-----	----

Does your child take any medication?	Yes	No
--------------------------------------	-----	----

If yes, please specify _____

Do you know if your child's hearing loss is due to:

Problems with the pregnancy, e.g. German measles?

Problems with the delivery, e.g. cord around the neck, foetal distress?

Problems that occurred after the birth, e.g. septicaemia, meningitis, severe jaundice, premature/low birth weight? _____

Appendix E

Questionnaire regarding your child's health (normal hearing)

Name of child: _____ Date of birth: _____

Phone number: _____ Age: _____

Please tick the appropriate answer:

Has your child ever had a head injury?	Yes	No
----------------------------------------	-----	----

Did your child have meningitis?	Yes	No
---------------------------------	-----	----

Did your child have encephalitis?	Yes	No
-----------------------------------	-----	----

Has your child ever had a fit?	Yes	No
--------------------------------	-----	----

Does your child have any visual problems?	Yes	No
-------------------------------------------	-----	----

Does your child have any hearing problems?	Yes	No
--------------------------------------------	-----	----

Were learning difficulties identified by your child's teacher?	Yes	No
----------------------------------------------------------------	-----	----

Has your child been diagnosed with cerebral palsy?	Yes	No
----------------------------------------------------	-----	----

Does your child take any medication?	Yes	No
--------------------------------------	-----	----

If yes, please specify

Appendix F



UNIVERSITY OF CAPE TOWN

Health Sciences Faculty
Research Ethics Committee
Room E52-24 Groote Schuur Hospital Old Main Building
Observatory 7925
Telephone [021] 406 6338 • Facsimile [021] 406 6411
e-mail: nositywabi@uct.ac.za

02 September 2008

REC REF: 320/2008

Mrs W Geldenhuys
Health & Rehab Sciences
OMB, Groote Schuur Hospital

Dear Mrs Geldenhuys

PROJECT TITLE: THE RELATIONSHIP BETWEEN MOTOR PERFORMANCE, BILATERAL VESTIBULAR HYPOFUNCTION AND VISUAL ACUITY IN CHILDREN WITH CONGENITAL OR EARLY ACQUIRED HEARING LOSS.

Thank you for submitting your study to the Research Ethics Committee for review.

It is a pleasure to inform you that the Ethics Committee has formally approved the above mentioned study.

Approval is granted until 03 September 2009.

Please note that the ongoing ethical conduct of the study remains the responsibility of the principal investigator.

Please quote the REC REF in all your correspondence.

Yours sincerely

signature removed

PROFESSOR M BLOCKMAN
CHAIRPERSON, HSF HUMAN ETHICS

This serves to confirm that the University of Cape Town Research Ethics Committee complies to the Ethics Standards for Clinical Research with a new drug in patients, based on the Medical Research Council (MRC-SA), Food and Drug Administration (FDA-USA), International Convention on Harmonisation Good Clinical Practice (ICH GCP) and Declaration of Helsinki guidelines.

10/09/08

Appendix G



SONITUS
SKOOL o SCHOOL

ONDERWYS AAN LEERDERS MET GEHOORGESTREMDHEID
EDUCATION FOR LEARNERS WITH HEARING DISABILITIES

15408, Lynn East, Pretoria 0009 • ☎ (012) 800-1161/2/3/4 • Fax: (012) 800-1170
e-mail: 220517@intekom.co.za

VERW/REF:

Navorsing by Sonitusskool: Fisioterapeut

Me. Willemien Geldenhuys het toestemming gehad om haar studie getiteld: "The relationship between motor performance, bilateral vestibular hypofunction and visual acuity in children with congenital or early acquired sensorineural hearing loss" by Sonitusskool uit te voer.

Dit was in die tydperk 2008 en die koördineerder by die skool was me Celeste Mulder (spraakterapeut en audioloog). Alle ouers is ingelig en moes die nodige skriftelike toestemming verleen sodat hulle kinders aan die studie mag deelneem.

Die resultate sal aan die ouers verskaf word en kan ook gebruik word in die skoolsisteem.

Skakel ons gerus indien u enige verdere inligting benodig.

Groete

signature removed

HOOF
RICHARD BETHU

signature removed 01/12/2009

AUDIOLOG
CELESTE MULDER

Appendix H

Information leaflet for children with a hearing loss at a school for the deaf

Dear Parent

Your child with a hearing loss is invited to volunteer for a research study. This information leaflet is to help you to decide if you would like your child to participate. The study has been approved by the Research Ethics Committee of the University of Cape Town and permission to do the study at Sonitis was obtained by the Gauteng Department of Education. Before you agree you should fully understand what is involved. If you have any questions, which are not fully explained in this leaflet, do not hesitate to ask me.

Explanation of procedures to be followed

This study involves answering some questions with regards to your child's health and hearing as well as testing his/her motor skills, vision and balance.

What is the purpose of this study?

The balance organ in the ear helps to stabilise the eyes. This gaze stability is necessary for being able to see clearly and to be able to read. In children with a hearing loss the balance organ in the ear may not function optimally. The main purpose of the study is to test the reliability of tests that is used to evaluate the balance organ in the ear, motor skills and clarity of vision.

- Motor skills will be tested by asking your child to do several activities like walking on a line, catching a ball, etc.
- The function of the balance organ in the ear will be tested by rotating your child on an office chair with special lenses on his/her eyes. These lenses will enlarge the eyes to make any eye movements easier to observe. The chair will then be stopped and your child's eye movements will be observed. After two minutes the test will be repeated by rotating the chair to the other side.
- To test the ability to see clearly, your child will be asked to identify symbols while his/her head is moving.

The tests will be done by two different investigators on the same day. We want to see if both investigators get the same results. The tests will then be repeated by one of the investigators on a different day.

There are no risks involved in this study. The only discomfort will be that you child will experience some dizziness for a few seconds after the rotations on the chair. These tests are safe and children usually enjoy it. Verbal assent will be obtained from the child prior to all activities. Your child can withdraw from the study at any time if he/she doesn't want to participate without any explanation. Withdrawal will not be held against the child and he/she will not be affected negatively due to the withdrawal.

All information obtained in this study will be regarded as confidential. Your child will receive a number and the identity of the children will only be known by me. No one else will have access to the identity of children participating in this study. Data that may be reported in scientific journals will not include any information which identifies your child as a participant in this research. Results will be revealed to the school principal without identifying individual children.

Twenty children between the ages of 4 and 12 years will be selected from the group of whom the parents/guardians gave consent. The selection will be based on the availability of the children and their willingness to participate in the activities. The tests will take about an hour to complete. Primary school children will be evaluated after school hours at the school. Pre-school children will be evaluated during school hours at the school. There will be no payment for taking part in the study.

Informed consent

I, ----- (full name and surname) parent/guardian of -----
----- (child's full name and surname) hereby grant permission that that my
child may participate in the above mentioned research study.

Parent/guardian(s) name: ----- (please print)

Parent/guardian(s) signature: ----- Date: -----

Child's name: ----- (please print)

Child's signature: ----- Date: -----

(Minors competent to understand must participate as fully as possible in the entire procedure.)

Contact details:

Principal investigator: Willemien Geldenhuys: 083 442 8258

012 335 0454

Supervisor: Prof. Jennifer Jelsma

Division of Physiotherapy

School of health and Rehabilitation Sciences

Faculty of Health Sciences

University of Cape Town

Tel: 021 406 6401

E-mail: jennifer.jelsma@uct.ac.za

Co-supervisor: Mrs Christine Rogers

Division of Communication Sciences and Disorders

Faculty of Health Sciences

University of Cape Town

Tel: 021 406 6315

E-mail: christine.rogers@uct.ac.za

UCT Ethics Committee: Chairperson, Faculty of Health Sciences

Research Ethics Committee

E52–23 Old Main Building, Groote Schuur Hospital

Observatory 7925

Tel: 021 406 6492; Fax: 021 406 6411

Regards

Willemien Geldenhuys Physiotherapist (083 442 8258)

Appendix I

Assent form for children to participate in research

Dear Boy/Girl

I want to learn more about how children see and balance and I need you to help me. I want to explain to you what I want to do and ask you to take part in this project.

Deep in your ear you have the part that helps you to hear sound. It looks like a snail shell. In children who are deaf this part doesn't work properly. Very close to this snail shell part of the ear are three tubes. These tubes are connected to your eyes and it helps you to see clearly when your head is moving. The tubes also help you to balance and stay upright. Because these tubes are so close to the snail shell part of the ear, we think that the tubes might also not work properly in children who are deaf. In my project I want to test the tubes in the ear, your ability to see when your head is moving and your balance. These tests are fun and most children enjoy them.

To test the tubes you will sit on a chair that can turn. You will wear a set of spectacles that looks like diving goggles. The goggles will help me to see your eyes better. You will also wear a safety belt to make sure that you feel safe on the chair. You will then keep your eyes closed and I will spin you ten times on the chair in one direction. Then I will stop the chair and I will tell you to open your eyes. I will watch your eyes for a few seconds. You will feel a bit dizzy after this test. I will then turn you to the other side.

I will then show different shapes on a chart to you. These shapes are easy to recognise. There are four different shapes: a circle, an apple, a square and a house. If you wear glasses you must wear them for this test. I want you to tell me what the shapes are with your head kept still. I will then move your head from side to side while you tell me again what the shapes are.

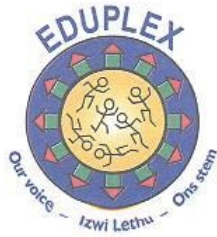
To test your balance we will play different games like walking on a line, catching a ball and threading a lace.

If you don't want to finish any of these tests you can just tell me that you want to stop and I will allow you to.

If you are willing to take part in the project please sign your name on the line.

Name: _____ Date: _____

Appendix J



15 April 2009

WIE DIT MAG AANGAAN

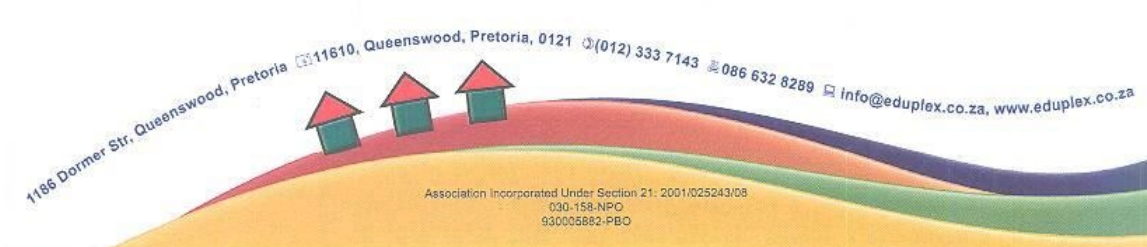
Hiermee word toestemming verleen aan Me. W. Geldenhuys om navorsing vir 'n Magistergraad in fisioterapie, soos uiteengesit in die Protokol wat aan ons voorgelê is, by die Eduplex te doen.

Die uwe

signature removed

J.J. de Goede

Prinsipaal



Appendix K

INFORMATION LEAFLET FOR CHILDREN WITH A HEARING LOSS AND INFORMED CONSENT

Introduction

Your child with a hearing loss is invited to volunteer for a research study. This information leaflet is to help you to decide if you would like your child to participate. The study has been approved by the Research Ethics Committee of the University of Cape Town and the ethics committee of The Eduplex. Before you agree you should fully understand what is involved. If you have any questions, which are not fully explained in this leaflet, do not hesitate to ask me.

What is the purpose of this study?

The balance organ in the ear helps to stabilise the eyes. This gaze stability is necessary for being able to see clearly and to be able to read. In children with a hearing loss the balance organ in the ear may not function optimally. The main purpose of the study is to test the motor skills and vision of children with a hearing loss and to compare it to the motor skills and vision of children with normal hearing. This means that children with a hearing loss may have reduced motor skills and reading problems, because their vision may be blurred. If a positive relationship is found, in future there is a chance that motor skills and visual acuity might be improved by means of therapy.

Explanation of procedures to be followed

This study involves answering some questions with regards to your child's health and hearing as well as doing some tests on his/her motor skills, balance and vision.

- Motor skills will be tested by asking your child to do several activities like walking on a line, catching a ball, etc.
- The function of the balance organ in the ear will be tested by rotating your child on an office chair with special lenses on his/her eyes. These lenses will enlarge the eyes to make any eye movements easier to observe. The chair will then be stopped and your child's eye movements will be observed. After two minutes the test will be repeated by rotating the chair to the other side.

- To test the ability to see clearly your child will be asked to identify symbols while his/her head is moving.

There are no risks involved in this study. The only discomfort will be that you child will experience some dizziness for a few seconds after the rotations on the chair. All activities and tests are safe and children usually enjoy it. Your child will have each activity explained and will be asked if he/she is willing to help and try the activity. Your child can withdraw from the study at any time if he/she doesn't want to participate without any explanation. Withdrawal will not be held against the child and he/she will not be affected negatively due to the withdrawal.

All information obtained in this study will be regarded as confidential. Your child will receive a number and the identity of the children will only be known by me. No one else will have access to the identity of children participating in this study. Data that may be reported in scientific journals will not include any information which identifies your child as a participant in this research. Results will be revealed to the school principal without identifying individual children.

All children of whom the parents/guardians gave consent and meet the inclusion criteria will be included in the study.

Tests will take about one hour to complete. Primary school children will be evaluated after school hours at the school. Pre-school children will be evaluated during school hours at the school. There is no payment for taking part in the study. After your child has completed the tests you will be informed about his/her performance. If necessary, we will give you advice if further treatment is needed.

Informed consent

I ----- (full name and surname) parent/guardian of -----
----- (child's full name and surname) hereby grant permission that that my
child may participate in the above mentioned research study.

Parent/guardian(s) name: ----- (please print)

Parent/guardian(s) signature: ----- Date: -----

Child's name: ----- (please print)

Child's signature: ----- Date: -----

(Minors competent to understand must participate as fully as possible in the entire procedure.)

Contact details:

Principal investigator: Willemien Geldenhuys: 083 442 8258

012 335 0454

Co-supervisor: Mrs Christine Rogers

Division of Communication Sciences and Disorders

Faculty of Health Sciences

University of Cape Town

Tel: 021 406 6315

E-mail: christine.rogers@uct.ac.za

UCT Ethics Committee: Chairperson, Faculty of Health Sciences

Research Ethics Committee

E52–23 Old Main Building, Groote Schuur Hospital

Observatory 7925

Tel: 021 406 6492; Fax: 021 406 6411

Regards

Willemien Geldenhuys Physiotherapist (083 442 8258)

Appendix L

INFORMATION LEAFLET FOR NORMAL HEARING CHILDREN AND INFORMED CONSENT

Dear Parent

Your child is invited to volunteer for a research study. This information leaflet is to help you to decide if you would like your child to participate. The study has been approved by the Research Ethics Committee of the University of Cape Town and the ethics committee of The Eduplex. Before you agree you should fully understand what is involved. If you have any questions, which are not fully explained in this leaflet, do not hesitate to ask me.

What is the purpose of this study?

The balance organ in the ear helps to stabilise the eyes. This gaze stability is necessary for being able to see clearly and to be able to read. In children with a hearing loss the balance organ in the ear may not function optimally. This means that children with a hearing loss may have reduced motor skills and reading problems, because their vision may be blurred. The main purpose of the study is to test the motor skills and vision of children with a hearing loss and to compare it to the motor skills and clarity of vision of children with normal hearing. Your child will be part of the control group. If a positive relationship is found, motor skills and visual acuity might be improved by means of therapy.

Explanation of procedures to be followed

This study involves answering some questions with regards to your child's health and hearing as well as testing his/her, motor skills, vision and balance.

- Motor skills will be tested by asking your child to do several activities like walking on a line, catching a ball, etc.
- The function of the balance organ in the ear will be tested by rotating your child on an office chair with special lenses on his/her eyes. These lenses will enlarge the eyes to make any eye movements easier to observe. The chair will then be stopped and your child's eye movements will be observed. After two minutes the test will be repeated by rotating the chair to the other side.

- To test the ability to see clearly, your child will be asked to identify symbols while his/her head is moving.

There are no risks involved in this study. The only discomfort will be that you child will experience some dizziness for a few seconds after the rotations on the chair. All activities and tests are safe and children usually enjoy it. Your child will have each activity explained and will be asked if he/she is willing to help and try the activity. Your child can withdraw from the study at any time if he/she doesn't want to participate without any explanation. Withdrawal will not be held against the child and he/she will not be affected negatively due to the withdrawal.

All information obtained in this study will be regarded as confidential. Your child will receive a number and the identity of the children will only be known by me. No one else will have access to the identity of children participating in this study. Data that may be reported in scientific journals will not include any information which identifies your child as a participant in this research. Results will be revealed to the school principal without identifying individual children.

Tests will take about one hour to complete. Primary school children will be evaluated after school hours at the school. Pre-school children will be evaluated during school hours at the school. There is no payment for participation.

Children in the control group will be matched to the group with impaired hearing according to age and gender.

If any impairment in your child's motor performance or vision is picked up during the tests we will let you know and give advice as to what you should do.

Informed consent

I, ----- (full name and surname) parent/guardian of -----
----- (child's full name and surname) hereby grant permission that that my child may participate in the above mentioned research study.

Parent/guardian(s) name: ----- (please print)

Parent/guardian(s) signature: ----- Date: -----

Child's name: ----- (please print)

Child's signature: ----- Date: -----

(Minors competent to understand must participate as fully as possible in the entire procedure.)

Contact details:

Principal investigator: Willemien Geldenhuys: 083 442 8258

012 335 0454

Co-supervisor: Mrs Christine Rogers

Division of Communication Sciences and Disorders

Faculty of Health Sciences

University of Cape Town

Tel: 021 406 6315

E-mail: christine.rogers@uct.ac.za

UCT Ethics Committee: Chairperson, Faculty of Health Sciences

Research Ethics Committee

E52–23 Old Main Building, Groote Schuur Hospital

Observatory 7925

Tel: 021 406 6492; Fax: 021 406 6411

Regards

Willemien Geldenhuys Physiotherapist (083 442 8258)